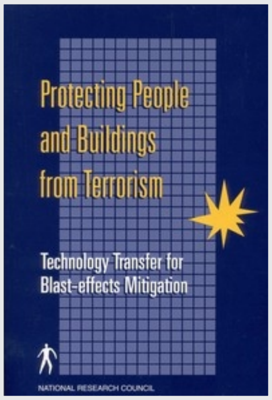

Protecting People and Buildings from Terrorism: Technology Transfer for Blast-effects Mitigation

DETAILS

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Technology Transfer for Blast-effects Mitigation

Committee for Oversight and Assessment of Blast-effects and Related Research

Board on Infrastructure and the Constructed Environment

Division on Engineering and Physical Sciences

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Preface

The report that follows was completed in July 2001. It is an effort to find ways and means for the civilian infrastructure to benefit from the technology developed in the course of the Blast Mitigation for Structures Program of the U.S. Department of Defense. As of September 11, 2001, the arithmetic governing the intersection of probability and harmful consequence has gone totally out of reckoning. What the Committee for the Oversight and Assessment of Blast-effects and Related Research considered and thought to be unthinkable threats have paled in comparison with what actually came to pass. The recommendations in this report, originally addressed to the prudent and potentially targeted, have now assumed compelling urgency for us all.

The overall concern of the committee for appropriate and balanced action to protect people in buildings has not changed. There is a host of nonintrusive changes in construction techniques, materials, and building management practices that will result in the least harm to architectural expression and cost and provide the greatest good for protection. Some of the solutions, active and passive, are already directly evident in the results of the Blast Mitigation for Structures Program. In this report the committee makes recommendations for appropriate mechanisms to achieve effective and rapid transfer of research results and existing technologies to the civilian infrastructure.

With the wish that none of the precautionary methods developed and solutions implemented will ever be needed, the committee importunes governmental bodies and the industries to rethink their building codes and sponsor development of the necessary and appropriate techniques to ensure that attractive and functional buildings can fulfill their first duty of protecting the people within them.

Mete Sozen, *Chair*
Committee for the Oversight and Assessment of Blast-effects and Related Research

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

John Chapman, Karn Charuhas Chapman & Twohey,
Andrea Dargush, Multidisciplinary Center for Earthquake Engineering Research,
Timothy E. Davis, National Center for Injury Prevention and Control,
John Haltiwanger, University of Illinois at Urbana-Champaign,
Jeremy Isenberg, Weidlinger Associates, Inc.,
John Karagozian, Karagozian and Case Structural Engineers, and
Christopher Rojahn, Applied Technology Council.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Lloyd A. Duscha, National Academy of Engineering. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Acronyms

ACI	American Concrete Institute
AIA	American Institute of Architects
AISC	American Institute of Steel Construction
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ATC	Applied Technology Council
ATF	Bureau of Alcohol, Tobacco, and Firearms
BMAG	Blast Mitigation Action Group
BSSC	Building Seismic Safety Council
CCB	Construction Criteria Base
COSEPUP	Committee on Science, Engineering, and Public Policy
COTS	commercial off-the-shelf
DARPA	Defense Advanced Research Projects Agency
DoD	U.S. Department of Defense
DTRA	Defense Threat Reduction Agency
DTRIAC	Defense Threat Reduction Information Analysis Center
FBI	Federal Bureau of Investigation
FEMA	Federal Emergency Management Agency
FFC	Federal Facilities Council

NEHRP	National Earthquake Hazard Reduction Program
NIST	National Institute of Standards and Technology
NRC	National Research Council
NSF	National Science Foundation
SAVIAC	Shock and Vibration Information Analysis Center
TSWG	Technical Support Working Group

Executive Summary

Concerned with the vulnerability of U.S. civilian and military personnel to terrorist bombing attacks, the U.S. Congress directed the Department of Defense to undertake a comprehensive research and testing program aimed at protecting people in buildings from such attacks. The Blast Mitigation for Structures Program was initiated in 1997 and has produced a large volume of experimental and analytical data that will permit the design of new, more robust buildings as well as the development of methods to retrofit a large number of vulnerable existing structures. The Blast Mitigation for Structures Program has involved numerous defense and civilian government agencies, private contractors, and product manufacturers (and to a lesser extent, universities) in a cooperative effort to identify needs and develop solutions.

Overall, the Committee for Oversight and Assessment of Blast-effects and Related Research believes that the Blast Mitigation for Structures Program offers a great opportunity to save lives and reduce injuries resulting from a terrorist bombing. The full benefits of the program will be realized, however, only if the results are widely disseminated and necessary improvements implemented. The committee has focused on a process that would use existing institutional infrastructures (i.e., building code and standards-writing organizations, professional and technical organizations, universities, and research centers) to disseminate knowledge. The committee believes that technology transfer for this purpose falls within the Defense Threat Reduction Agency (DTRA) mission and that the Blast Mitigation for Structures Program could readily adapt the model already developed and used by the earthquake engineering community. Issues exist regarding the security of sensitive information, but the committee believes that they are resolvable and should not become an impediment to the effective, timely, and necessary transfer of information.

As the committee was completing its work, the Federal Emergency Management Agency (FEMA), at the direction of the President, established the Office of National Preparedness at FEMA to serve as the focal point for the federal coordination and implementation of preparedness, training, exercise, and consequence management programs for dealing with the threat of weapons of mass destruction. The committee notes that FEMA serves as a clearinghouse for hazard mitigation and emergency preparedness information developed under the National Earthquake Hazard Reduction Program (among others), provides training to first responders and emergency services personnel for a variety of natural and technological hazards, and supplies technical guidance in hazard-resistant design to engineers and architects. The committee believes that the Blast Mitigation for Structures Program could be a valuable informational and training resource for this new FEMA organization and that FEMA could assist DTRA with technology transfer activities. In any event, this is a potentially powerful governmental partnership that should be explored.

CONCLUSIONS

The committee reached the following conclusions regarding what it believes are the most pressing and fundamental questions related to the dissemination of blast-effects information.

1. In light of world conditions, as amplified by the events of September 11, 2001, that suggest a continuing terrorist threat to the United States and its citizens, the engineering and architectural professions have an ongoing need for blast-effects design guidance.
2. Promoting technology transfer of the results of the Blast Mitigation for Structures Program falls within the mission of the Defense Threat Reduction Agency to ". . . safeguard America and its friends from weapons of mass destruction."
3. DTRA has tended to focus on military applications of the outputs of the Blast Mitigation for Structures Program, but the committee believes that to achieve maximum effectiveness in realizing the goal of "protecting people in buildings," the results of the program should be targeted to nondefense government agencies and the civilian design and building community, i.e., the nonspecialists in protective design.

4. Because interaction with the client/owner in a civilian building project most often occurs through the architect/engineer—and it is often left to the architect/engineer to explain the design philosophy inherent in blast-resistant construction, its potential multi-hazard benefits, and cost tradeoffs—architects/engineers have a critical role to play in the practical diffusion of new knowledge and approaches for blast-effects mitigation.
5. The requisite level of knowledge will vary depending on the role of the engineer or architect in an individual project and the nature of that project. However, at a minimum, all building design professionals involved with buildings potentially subject to blast effects should be familiar with how structures are affected by explosions (loading and response of structural and nonstructural systems), blast-effects mitigation measures, and basic life safety considerations. Specific design problems may require higher levels of knowledge and some may be addressed only by a specialized blast engineer. This should not be construed to imply that all blast problems are the province of the specialist; qualified design professionals properly guided by up-to-date information can adequately address many blast-related issues.
6. Engineers and architects involved with blast-resistant design require information that will allow them to translate security objectives for a given facility into performance requirements for the building and site. Performance requirements must be the product of a multiobjective decision process that includes risk and cost factors. Essential to developing design solutions that will achieve the performance requirements is knowledge of such varied topics as, for example, the purpose and value of standoff;[1] the effectiveness of vehicle barriers and other methods for screening the building, its entrances and exits, and its occupants from potential attackers; the performance of reinforcement splices, column wrappings, and other structural retrofit methods; the performance of glazing materials, window systems, vents, and doors; the design, selection, and arrangement of interior, nonstructural features such as furniture, office equipment, and overhead fixtures, to prevent them from becoming agents of additional damage or injury; and the means of facilitating the rescue of the building's occupants in the event of an attack. There is also a need for simplified design guidance for lesser hardening and moderate hardening levels of blast-resistant design.

[1]Standoff is generally understood to be the distance between the detonation point of a bomb and the target building.

7. Information sources can and should take many forms. These will include published conference papers, technical letters and manuals, Web pages, workshops, symposia, and short courses. Technology transfer is an ongoing process; to be successful it must be continuously evaluated and updated to match the needs of the user with the capabilities of emerging technology. Both will evolve over time.
8. Significant work in structural systems and materials that has been underway for many years in U.S. research universities could advance the objectives of the Blast Mitigation for Structures Program, but the program has not taken full advantage of these capabilities.
9. The private sector is much more cost sensitive than the military or civilian federal sectors. Cost and market demands are very likely to determine what, if anything, is done to protect commercial buildings and their occupants from bombing attacks. In the committee's judgment, the cost sensitivity of the private sector can best be addressed by a multihazard approach to blast-effects mitigation, particularly in the case of building retrofits, that will provide collateral protection against other hazards such as earthquakes, extreme wind events, fire, and flood.
10. There is a need to develop a decision framework that will permit military installations, government agencies, and commercial building owners to implement necessary security and blast- and natural hazard-mitigation practices based on a balanced assessment of threats, building vulnerabilities, acceptable risks, and available resources. This framework should include accurate and up-to-date cost-estimating information for various levels of protection that can be applied to both new and retrofit construction.
11. With appropriate precautions, the design guidance for blast-effects mitigation that would be most useful to the engineering and architectural communities can be disseminated in a form that will not compromise sensitive information and aid terrorists.

RECOMMENDATIONS

The committee believes that the Defense Threat Reduction Agency (DTRA) is uniquely positioned to make its mission objective of "protecting people in buildings" a reality. The agency has carried out a focused and valuable program of research and testing, engineering analysis, and computational modeling to supplement a formidable body of existing knowledge on blast effects and blast-resistant construction. Although much work still remains to be done, much of value has already been completed. However, the full benefits of this effort will be realized only if the technology is *implemented,* and this requires that the information developed be made broadly available to all those in a position to utilize it. For this reason, the committee offers the following recommendations for technology transfer of the results of the Blast Mitigation for Structures Program.

1. DTRA should take a leadership position in facilitating the implementation of the comprehensive technology transfer strategy articulated throughout this report. This includes the development and dissemination (for unrestricted release) of specific products (e.g., design and cost-estimating guides, assessment tools, databases); encouragement of the presentation and publication of research results and potential applications in mainstream civilian (as opposed to defense-oriented) engineering and architectural conferences and journals; support of venues for the meeting and interaction of researchers and practitioners such as technical committees, conference sessions, symposia, and workshops; support of a product database of materials linked to blast performance specifications; and maintenance of outreach services through print or Web-based newsletters. The committee believes that technology transfer is an integral component of the Blast Mitigation for Structures Program and that sufficient funds should be set aside by DTRA or others to establish and sustain the effort.
2. DTRA should contract with an organization familiar with technology transfer to manage the activity on DTRA's behalf. Organizations that have performed similar functions include the Applied Technology Council (earthquake and wind engineering), DoD information analysis centers such as the Shock and Vibration Information Analysis Center (SAVIAC) and DTRA's Nuclear Weapons Effects Information Analysis Center (DTRIAC), and several private contractors that operate information clearinghouses for government programs. The Construction Criteria Base (CCB) is published quarterly on CD-ROM by the National Institute of Building Sciences and contains construction-related documents from 22 federal agencies and 110 industry organizations. The CCB may be useful in making blast-mitigation technology available to a wide audience of design professionals.
3. The Blast Mitigation for Structures Program should survey and evaluate relevant ongoing university research with the objective of identifying and synthesizing what may be of value for improving the performance of buildings in a blast environment and also consider universities for direct participation in the research effort.
4. The Blast Mitigation for Structures Program technology transfer effort should emphasize techniques and products for the retrofit of

existing buildings and take advantage of the opportunities thus presented to achieve protection against multiple hazards such as earthquakes, extreme wind events, fire, and flood, as well as blast effects.

5. Implementation of blast mitigation measures should be based on established risk management principles. The Blast Mitigation for Structures Program should develop a performance-based, multi-objective design process for federal facilities that integrates security and natural hazard mitigation objectives with new technologies and is based on building mission, defined threat, acceptable risk, and available resources.
6. To gather valuable and perishable medical data, the Blast Mitigation for Structures Program should support the establishment within an appropriate agency (e.g., Centers for Disease Control and Prevention, FEMA, Bureau of Alcohol, Tobacco, and Firearms) of rapid response data-gathering teams to investigate bombing attacks that may occur in the future. The data collected by these teams should be integrated with information from past events and made available to researchers and practitioners in emergency medicine, injury epidemiology, search and rescue, architecture, and engineering.
7. DTRA should establish an interagency committee composed of both military and civilian members to provide customer input on the content and conduct of the technology transfer effort. Alternatively, DTRA could make use of the Physical Security and Hazard Mitigation Committee recently established by the Federal Facilities Council of the National Research Council to provide this service. The committee believes that it is important to establish and maintain a forum for customers and potential customers of the Blast Mitigation for Structures Program (such as the newly established Office of National Preparedness at FEMA) to provide feedback to both the research and the technology transfer components of the program.

1

Introduction

BACKGROUND

Terrorist attacks aimed at the United States and its citizens represent a serious, ongoing threat. The 1990s were marked by a series of vehicle bomb attacks, inflicted domestically and overseas, that claimed many lives and left many more people crippled and injured. At the direction of the U.S. Congress, the Defense Threat Reduction Agency (DTRA), under the sponsorship of the Department of Defense (DoD) Technical Support Working Group (TSWG), initiated the Blast Mitigation for Structures Program "to protect people inside buildings from terrorist bomb attacks" (DTRA, 1999). To accomplish the objective of saving lives and reducing injuries, DTRA embarked on a comprehensive research and testing program aimed at increasing the understanding of how buildings, and their structural and nonstructural components and systems, respond to blast-induced loadings, and how this performance can be improved.

In a 1995 report, *Protecting Buildings from Bomb Damage: Transfer of Blast-Effects Mitigation Technologies from Military to Civilian Applications* (NRC, 1995), a committee of the National Research Council (NRC) found that much of the structural research and testing that had been done in support of military missions during the Cold War was generally applicable to civilian design practice and could help to mitigate the effects of terrorist bombs. At the same time, the committee also recognized that to be broadly effective, this body of work would have to be expanded and presented in a form that was more readily usable by a diverse audience of design, construction, building management, and security professionals. The 1995 report's authoring committee believed that establishing a formalized process for knowledge and technology transfer of blast-effects research was a critical step in improving the performance of civilian buildings, minimizing casualties, and facilitating rescue and recovery operations in cases of terrorist bombing attacks.

INVOLVEMENT OF THE NATIONAL RESEARCH COUNCIL

Due to its long familiarity with these issues, the NRC was asked to review the Blast Mitigation for Structures Program and offer recommendations for both conducting research and transferring technology to the military and civilian sectors. In response to that request, the NRC assembled an independent committee of experts, the Committee for Oversight and Assessment of Blast-Effects and Related Research, under the auspices of the Board on Infrastructure and the Constructed Environment. The 14 members of the committee have expertise in blast-effects research and testing, structural analysis and design, architectural and interior design, seismic safety, disaster preparedness and consequence management, emergency medical services, computer-based modeling and assessment techniques, building code development, and knowledge transfer. Biographical information about the committee members is provided in Appendix A.

STATEMENT OF TASK

The committee was asked to perform the following tasks:

(1) Assist in the development of a blast-effects research agenda and provide recommendations for activity priorities. This will include assessing the scope and focus of related, on-going research, both in this country and internationally, to assure that efforts are well-integrated; evaluating the capability of the existing research infrastructure to achieve research objectives; and determining the possible need for a national test facility to carry out the research program.
(2) Recommend appropriate mechanisms to achieve effective transfer of research results and existing technologies to civilian government agencies and commercial engineering and architectural practice.
(3) Develop recommendations for outreach and knowledge dissemination activities to be undertaken by DTRA and other agencies.
(4) Review and comment on proposed curriculum or training materials designed to enable civilian engineers and architects to apply the principles of protective design and analysis to civilian buildings and other constructed facilities.
(5) Provide a forum to enhance interaction and information sharing

among other stakeholder government agencies such as the General Services Administration, Federal Emergency Management Agency, U.S. Army Corps of Engineers, Centers for Disease Control and Prevention, Bureau of Alcohol, Tobacco, and Firearms, Department of Transportation, Department of State, etc., and state and local governments.

To address the first task, the committee completed a program review and issued a report in May 2000 (NRC, 2000). *Blast Mitigation for Structures: 1999 Status Report on the DTRA/TSWG Program* contained specific recommendations for the content and focus of the research program, several of which have been incorporated in the Blast Mitigation for Structures Program. In response to Task 5 and a recommendation contained in the committee's first report, the Federal Facilities Council (FFC) of the NRC has established the Physical Security and Hazard Mitigation Committee. The FFC is a cooperative association of 22 federal agencies established for the purpose of addressing issues of common concern. This new FFC committee is seen as a potential vehicle for both disseminating the output of the Blast Mitigation for Structures Program and identifying additional needs of the user community. Tasks 2 through 5 of the committee's charge are addressed in the current report.

PROTECTING PEOPLE AND BUILDINGS FROM BOMB DAMAGE

To enhance its level of understanding of potential user needs for the output of the Blast Mitigation for Structures Program and the best means of providing it, the committee convened a 3-day workshop in Washington, D.C., in November 2000 (Appendix B gives the workshop agenda). The workshop was attended by 90 representatives of government, industry, and academia from the United States and the United Kingdom who constituted a broad group of stakeholders for the results of the Blast Mitigation for Structures Program. The purpose of the workshop was to do the following:

- Present the work, results, and opportunities offered by the Blast Mitigation for Structures Program and determine the information needs of the owner, user, and provider communities.
- Identify appropriate mechanisms and venues for discrete and continuous information sharing.

The workshop was broadly organized to address the perspectives and needs of the four user groups that the committee believed to be most concerned with the issues of blast-effects mitigation: the building owner and user community; architects and building system designers; structural engineers and designers; and the emergency medicine and search and rescue community. A plenary panel discussed activities ongoing within several organizations, agencies, and universities and how these efforts could facilitate knowledge and technology transfer. The final day of the workshop featured panel reports summarizing the perspectives of the four stakeholder groups and offering observations and recommended actions for the committee and DTRA to consider.

The committee notes that the observations, findings, and recommendations presented in this report are based on the knowledge and experience of its members and on the discussions facilitated by the workshop. Although the participation of the workshop attendees was invaluable for the preparation of this report, the findings and recommendations represent the opinions of the NRC committee appointed to develop them.

ORGANIZATION OF THIS REPORT

The succeeding chapters in this report are organized broadly along the themes of the workshop. Chapter 2 outlines the information and technology needs identified at the workshop by the four stakeholder groups. Chapter 3 contains an overview of knowledge and technology transfer, including some historical perspective on the effectiveness of translating the results of engineering research into practice, and outlines the committee's recommended strategy for DTRA to follow for transferring the results of the Blast Mitigation for Structures Program broadly through the military and civilian sectors. The issue of dealing with sensitive or export-controlled technology is also discussed in Chapter 3. Chapter 4 contains the committee's conclusions and recommendations.

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2

Information and Technology Needs of Stakeholders

One purpose of the workshop "Protecting People and Buildings from Bomb Damage" was to bring together representatives of the various stakeholder groups to identify their needs for information and technology to improve the blast-resistance of buildings and reduce the likelihood of death and injury in the event of a terrorist bombing attack. During the course of the presentations and in the topical breakout sessions, workshop participants identified many issues of the civilian user community (and to a lesser extent the defense community). Some of the technology and information needed requires additional research (e.g., to address the performance of glazing materials and structural subassemblies in a blast environment), but other needs could be met by empirical studies of existing information (e.g., analysis of prior bombing events) or by adapting for civilian use design methods and approaches already developed for the military and documented in government manuals and design guides. A technology transfer strategy that links needs with proposed solutions is presented in Chapter 3.

Specific information and technology needs discussed at the workshop are presented below, organized according to the four stakeholder groups identified by the committee as the primary beneficiaries of the results of the Blast Mitigation for Structures Program—owners and users of buildings and facilities; building system (mechanical, electrical, and other) designers; structural designers; and emergency medicine and search and rescue personnel.

OWNERS AND USERS

Even though more than 250 bombing attacks against buildings were reported in 1997 (FBI, 1998), there had been, until the events of September 11, 2001, no recurrence of a domestic event of the magnitude of the bombing of the Alfred P. Murrah federal building in 1995. Whether in the public or private sector, most building owners and users still view the threat to domestic buildings from terrorist bombings as a high-consequence, low-probability event and thus find it difficult to provide and pay for the protective counter-measures suggested by threat and vulnerability analyses. Persuading decision makers to allocate resources to address potential threats from terrorist bombings is not a simple task. In the rare instance when a public or private sector building owner accepts the need for security measures against terrorist bombing threats, it is highly unlikely that resources will be available to fund all desirable measures or insurance credits provided to underwrite their cost.

For several reasons, the insurance industry is not likely to provide incentives for blast-mitigating building design, despite intuitive logic to the contrary. Losses from terrorist attacks have been very low in experience, and insurers are thus less likely to offer significant credits for well-protected risks. In addition, property insurance generally covers direct losses due to a terrorist attack—most specifically the cost of repairing or replacing the building. It has not covered difficult to quantify collateral losses such as lost market share, damage to corporate or product image, or loss of employee productivity during recovery, which can account for the largest potential economic impact on an affected property.

To overcome such barriers to increased support for blast-mitigation building design, many workshop participants suggested that research on blast-mitigation technology should maintain a broad perspective, focusing on blast-mitigation solutions that can be shown to apply to other hazards and that thus could be more readily accepted and deployed. Specific suggestions included the following:

- Ensuring that design measures for mitigation of blast effects are effective in other areas such as fire and life safety;
- Developing designs that can enhance survivability and facilitate emergency response in disasters of various kinds by, for example, providing buildings that can be used as areas of refuge or safe havens in the aftermath of blasts, fires, earthquakes, tornados, hurricanes, and other classes of emergencies; and
- Providing education and a rationale for building code authorities to include consideration of blast effects in code provisions where

these are consistent with the objectives of building and fire and life safety codes.

Although it is improbable that commercial building codes will mandate security and blast-effects mitigation measures, it would be appropriate for a code to stipulate that any measures undertaken to address security concerns must meet certain performance standards. Testing laboratories and certifying agencies routinely put forward such criteria, which could include provisions such as a requirement that if blast-resistant windows are installed, some percentage must be operable to permit ready egress for the occupants and access for rescue personnel. Workshop participants also suggested that the Blast Mitigation for Structures Program could investigate other performance objectives such as energy performance, sustainability, and the quality of the working environment that might make blast-effects mitigation measures more financially attractive. Benefit-cost analysis of blast-effects mitigation features could identify ancillary benefits that contribute to long-term savings over the life cycle of the improvements, such as maintenance and operations costs, occupants' productivity, reduction of occupants' risk of injury and death, and enhancement of the speed of recovery of the operation to reduce loss-of-use costs.

A major issue for building owners and managers, and a significant obstacle to planning the blast-effects mitigation component of a project, is the lack of readily available and accurate cost-estimating methods. This gap was noted in earlier work by the NRC that recommended the following:

> Analyze all new civilian federal buildings, and existing buildings where appropriate, to determine reasonable ways of incorporating blast-hardening and other blast-effects mitigating features, and to document consequent building construction costs and financial performance. (NRC, 1995)

The committee notes that such data would lead owners, designers, and managers to sources of costs and guides for estimating how much different levels of protection would cost. However, to date, the compilation and study of costs from past projects have not been done systematically.

BUILDING SYSTEM DESIGNERS

Overall, the design community is seeking the development of a unified design approach that incorporates standard criteria for security objectives and a uniform definition of standoff. At the workshop, discussion of building systems also identified the need for a more multihazard design approach and benefit-risk methods to assess the true value of mitigation measures over the lifetime of the building. The phenomena of explosions and collateral effects of blast and blast debris, particularly in multiple building configurations, are not well understood by most building system designers. Technical questions arise regarding reflection of the blast wave and how this can affect adjacent buildings. Considerable interest was expressed in how earthquake-resistant designs would perform under blast loading. While blast loading of buildings differs in character from seismic loading, some mitigation principles are applicable under both types of loading. The response of building systems such as water and sewer lines and sprinkler systems appears similar to responses experienced during earthquakes, but the potential of these systems to imperil occupants and impede rescue when they are damaged argues for some definitive statements of expected performance. The Blast Mitigation for Structures Program plans to study the relative performance of standard seismic designs under blast conditions, but little information is yet available.

A number of areas that require additional research were identified, such as site perimeter features, openings in a building's exterior envelope, and the collateral effects of blast and blast debris. Widespread desire was expressed by workshop participants for a better understanding of:

- Design options for a variety of vehicle barriers;
- The value of blast barriers in attenuating blasts and sheltering buildings from blast effects;
- Design for support of the efforts of rescue and emergency services;
- Techniques for perimeter controls;
- Design of flexible and movable perimeter-access controls, such as gates and other features; and
- Retrofitting of features such as bollards to be installed over existing vaults or other underground spaces at the perimeter barrier.

Information and guidance are also desired for design options and products for openings in the exterior cladding of a building such as operable sashes, doors, louvers, skylights, and exterior hardware. As noted above, blast and its effects on both structural and nonstructural systems are not well understood by the design community. Questions were raised regarding the vulnerability of columns to smaller satchel-type charges, uplift effects of explosions on slabs, especially in mechanical equipment rooms with louvers, as well as design details for all building systems subject to blast. One strongly expressed need was for simplified procedures that would permit building system design professionals to identify and evaluate blast-effects mitigation options at the early stages of a project, particularly during consultation with the building's owner.

STRUCTURAL DESIGNERS

As pointed out at the workshop, structural designers' needs for information and guidelines parallel many of the issues raised by owners and users and by building system designers. For example, an overriding interest was expressed in obtaining access to guidelines for protective design, with an emphasis on obtaining up-to-date technical design manuals in the public domain that address differing levels of protective structures, especially in the following three categories:

- Lesser hardening (e.g., industrial and commercial facilities),
- Moderate hardening (e.g., General Services Administration and courthouses), and
- Greater hardening (e.g., State Department and Department of Defense facilities).

There was considerable interest in simplified design guidance for providing lesser to moderate levels of blast protective design in a cost-effective manner, particularly for retrofit construction. Two additional design issues that were specifically identified were criteria for and approaches to providing reasonable protection against progressive collapse from moderate-size blast events and the entire question of glazing—available materials, and methods for attaching glass to the frame, and the frame to the wall. Test data and access to the database for all products that have been tested to some performance specification are desired. This includes design methods for "hardening" existing masonry walls with such materials as polymer linings (RinoSkin), steel plates, and geotextile fabrics. More information regarding the ductility and effectiveness of various types of mechanical splicing of reinforcing steel when subjected to rapid strain rate loads is also desired.

Strong support was expressed for a program of short courses, seminars, and tutorial documents for professionals to enhance their knowledge of blast protective design. This would include basic screening and design approaches for blast-hardened structures as well as pragmatic and cost-effective approaches for preventing progressive collapse. Also discussed was the need for a risk-based methodology to help a building's owner and design team establish appropriate levels of hardening for a specific project. Such a methodology would establish a minimum desirable set of hardening goals for various types of facilities (i.e., reasonable levels of protective design and the cost of providing it) coupled with guidelines aimed at achieving these hardening goals.

EMERGENCY MEDICINE AND SEARCH AND RESCUE PERSONNEL

Five major issues affecting emergency medical care and search and rescue operations were identified at the workshop:

- Perishable injury and health data that could be used to save lives in future incidents is not routinely collected.
- Obtaining data that has been compiled on past bombings is difficult.
- Buildings are designed with little consideration for the needs of search and rescue operations and personnel.[1]
- Search and rescue operations are impeded by a general lack of knowledge about a building's design, utility shut-offs, and the probable locations of occupants and potential hazards.
- Search and rescue operations would be facilitated by the rapid availability of assessments of a damaged building's remaining structural integrity.

From the standpoint of emergency medicine, bombings constitute a double tragedy. The deaths, injuries, and property damage are obvious first-order effects. However, the failure to collect valuable, perishable data could also result in lives lost needlessly in future events. Several reasons were cited for the general failure to collect data: rescuers, survivors, and bystanders leave the scene; priority is given to administering medical care, not to collecting data; buildings are demolished and occupants relocated. In order to overcome the inherent barriers to collecting and compiling accurate medical data, it was suggested that multidisciplinary, rapid-response data collection teams be established. Such teams could be organized within existing incident response activities carried out by such federal agencies as the Centers for Disease Control and Prevention, the Federal Emergency Management Agency, or the Bureau of Alcohol, Tobacco, and Firearms. These groups would be analogous to the crash investigation teams fielded by the National Transportation Safety Board and would utilize specialists in emergency medical services, epidemiology, structural engineering, architecture, emergency management, and disaster research. They would apply standardized methods to collect data of potential use to medical responders, building designers, and injury prevention specialists.

The primary value of this database would be to prepare medical re-

[1]For example, design features that might provide protection against bomb damage (e.g., heavily reinforced concrete walls) may greatly impede efforts by rescuers to gain access to victims following an explosion.

sponders for the various causes of injury and illness that they might encounter (e.g., blast effects, glass, inhaled dust, shrapnel, structural collapse, smoke, carbon monoxide, asbestos or other toxic inhalants, angina heart attack). However, it would also serve several other purposes. Buildings are currently designed with little consideration for the needs of search and rescue personnel and operations. With better information available, search and rescue personnel would have an improved sense of where survivors seek refuge (or where and how they happen to survive) and how to extricate them quickly and safely. Rescue personnel would also have a better understanding of the hazards they face when entering a damaged building (e.g., unsecured electric and natural gas service, leaking sewage, airborne asbestos, and other hazardous substances). Detailed data on the epidemiology of blast-related injuries would also be of considerable value to the designers of future buildings, who could then use that information in the design and placement of equipment and services, emergency shut-off valves and switches, and areas of refuge and potential escape routes. Furthermore, accurate data on the injuries sustained by a building's occupants, combined with structural and nonstructural data on the location of victims at the time of an explosion, would be helpful in identifying mechanisms of injury and potential injury-reduction strategies. Overall, this was seen as an area where modest investments in pre-event planning could greatly improve the survivability of the victims of future events.

Although some data from past bombing events (in Oklahoma City, at the Khobar Towers, and in Nairobi and Dar es Salaam) have been collected and analyzed, the work has been done by several organizations. Collection methods have varied, as have the level and specificity of the data, which complicates the accessibility of the data and its comparability across events. At an even more basic level, researchers may not be aware of the existence of data from other events. Workshop participants discussed the concept of a national or international clearinghouse to serve as a repository for blast-related injury data from past and future events. The clearinghouse would be of great value to practitioners and researchers in emergency medicine, injury epidemiology, and building design.

Data collected promptly and stored in a retrievable form is only part of a solution to a truly multidisciplinary problem—how to use information effectively to reduce injuries, aid recovery, and save lives while, at the same time, not placing emergency personnel at excessive risk of injury, illness, or death. The key to developing and applying a truly holistic approach to safe, robust, and attractive building design is continued dialogue and interaction between medical, building design, and rescue and recovery specialists through conferences, seminars, and short courses. If each specialty understands the needs of the others and how their work affects and is affected by them, an effective system of lessons learned can be implemented.

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3

Translating Blast-effects Research into Practice

From the beginning of the committee's work in support of the Blast Mitigation for Structures Program, it was understood that the output of the program would have to be made available to a broad community of stakeholders in both the public and private sectors. Potential users of the information include engineers of various disciplines, architects, building owners and managers, construction contractors, materials and equipment suppliers, emergency responders, and medical personnel. DTRA understandably has tended to focus on military applications, but the committee believes that to achieve maximum effectiveness in realizing the goal of "protecting people in buildings," the results of the Blast Mitigation for Structures Program should be targeted to nondefense government agencies and the civilian design and building community, i.e., the nonspecialists in protective design.

Although the military and civilian sectors have essentially identical technical requirements, somewhat different technology transfer approaches are warranted for the military versus the civilian and commercial aspects of the program. For example, the private sector is much more cost sensitive than the military or civilian federal sectors. Cost and market demands are very likely to determine what, if anything, is done to protect commercial buildings and their occupants from bombing attacks. In the committee's judgment, the cost sensitivity of the private sector can best be addressed by a multihazard approach to blast-effects mitigation that will provide collateral protection against, for example, earthquakes and extreme wind events.

THE GOVERNMENT ROLE IN TECHNOLOGY TRANSFER

Technology transfer is an established process by which acquired knowledge is transferred to interested parties. As such, it is useful for the Blast Mitigation for Structures Program to be aware of the historic role of U.S. defense and other agencies in the technology transfer and knowledge dissemination process. Over the years since World War II, a U.S. model of technology development and subsequent transfer has evolved that has been described as having three attributes (COSEPUP, 1992):

- A high level of support for research by defense and other agencies,
- A prominent role for universities as performers of the research, and
- Minimal assistance for industrial technology adoption.

The Defense Advanced Research Projects Agency (DARPA) is considered a good example of a federal agency that sponsors defense-oriented research and is also successful as a research organization capable of technology transfer. The reasons cited for this success are the fact that DoD itself is the customer for the products of the research and that DARPA builds strong working relationships with its clients within DoD (COSEPUP, 1992). The nuclear weapons laboratories have been successful for similar reasons. The government, as "customer," has established the specifications or performance objectives, taken delivery of the final product, and been responsible for evaluating the product against the stated performance requirements. At each stage of the process, there are clear and well-defined linkages and feedback mechanisms, with ample opportunities for interaction between research and development activities and the ultimate consumer.

Successful technology transfer is goal-driven and the result of a cooperative association of the research, development, manufacturing, and user communities. Therefore, a key element of a Blast Mitigation for Structures Program technology transfer effort should be a periodic and systematized method for obtaining from the customer community (i.e., in the case of the Blast Mitigation for Structures Program, the military services, civilian agencies, state and local governments, and the private sector) a clear statement of issues, needs, and solution domains. Such communication could be promoted in several ways. Focus groups of interested private sector building owners could be convened on a regular basis by DTRA or another entity charged with technology transfer to provide direct input to the program. Sessions at conferences and other professional meetings are also valuable but are usually not as targeted as focus groups. To its credit, the Blast Mitigation for Structures Program has always demonstrated a strong customer orientation. Much of the research and testing done to date has been at the request of individual agencies with specific issues or problems. The committee believes that this customer focus should be sustained and enhanced with ample opportunities for all potential end users to play an active role in defining requirements and other aspects of product development.

The historic value of the U.S. model for technology transfer may be readily seen in certain industrial sectors that have benefited from spin-offs of defense-oriented, federally funded R&D, such as computers, semiconductors, airframes, and aircraft engines. The focus of technology transfer is changing, however, with increasing emphasis placed by the military and other government agencies on the use of commercial, off-the-shelf (COTS) technologies and products. The Blast Mitigation for Structures Program is in an excellent position to take advantage of the movement toward COTS technologies as most of the products being investigated are in the commercial sector. In this instance, the defense and civilian missions are nearly congruent, and there is little need to attempt the sometimes arduous task of "commercializing" a purely military product or application.

The emphasis on COTS applications does raise some programmatic questions for the Blast Mitigation for Structures Program, however. One of the characteristics of successful technology transfer activities is a strong relationship between the product developer and the customer (COSEPUP, 1992). For example, the degree to which the Blast Mitigation for Structures Program is (or should be) actively participating in product development or merely testing what is currently available is not clear to the committee. However, the committee sees a potentially vital role for the program in defining performance objectives for materials and products and encouraging industry to take an active role in developing them as well as participating in developing the scope of investigations and test programs. The Blast Mitigation for Structures Program also could help to design appropriate test methods and in certain cases, provide testing facilities (e.g., the controlled test structure and the large blast and thermal simulator at White Sands Proving Grounds).

The committee would favor a more activist role for the Blast Mitigation for Structures Program because the somewhat limited market for blast-effects mitigation products appears to provide little incentive for manufacturers to participate actively in a "technology push" type environment, absent clear and specific guidelines for new product development. The committee does believe, however, that manufacturers should accept some responsibility by submitting their products for testing and by publication of test results in their product literature. The Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academies underscored this point in its report on the government's role in civilian technology:

> Private companies have little financial incentive to invest in R&D that will be available outside the company and therefore involves significant problems in appropriability for the firm. It is when scientific inquiry involves the promise of useful new knowledge that is generic in nature, with wide applications across economic activities, and there are insufficient private returns on investments in R&D that government must act. (COSEPUP, 1992)

ACADEMIC INVOLVEMENT

In its prior report, the committee identified several potential research, training, and technology transfer roles for academia in the Blast Mitigation for Structures Program but does not believe that the program has taken full advantage of the capabilities of U.S. universities to participate in the program (NRC, 2000). The committee finds the lack of academic involvement unfortunate because the United States arguably possesses the world's most dynamic and productive system of university research. The committee believes that significant work in structural systems and materials that has been underway for many years in U.S. research universities could advance the objectives of the Blast Mitigation for Structures Program. This work should be evaluated with the objective of identifying and synthesizing what may be of value for improving the performance of buildings in a blast environment. In addition, university centers such as the Protective Technology Center at Pennsylvania State University and the National Center for Explosion Resistant Design at the University of Missouri-Columbia offer opportunities in research and training that could be valuable resources for the Blast Mitigation for Structures Program and its client agencies.

Universities also have a powerful, if indirect, role in technology transfer through the knowledge imparted to new graduates who will themselves become the next generation of practitioners. The NRC report *Protecting Buildings from Bomb Damage: Transfer of Blast-Effects Mitigation Technology from Military to Civilian Applications* emphasized the importance of addressing gaps in the education of design profession as a means of strengthening technology transfer for blast-effect mitigation:

> The committee has found that there are several serious barriers to technology transfer from the military to the civilian sector. The first major barrier is education. The current academic and professional training of architects and engineers does not adequately prepare the design professionals, either technically or philosophically, to incorporate blast-hardening principles in civilian structures. Thus, a strong educational commitment is required by university schools of architecture, construction, and engineering, as well as by professional engineering societies, if the potential for technology transfer is to be realized. (NRC, 1995)

The Blast Mitigation for Structures Program could assist universities in closing the training gap and make a significant contribution to technology transfer by encouraging and supporting course work in blast-resistant design. Training could be supplemented by university involvement in research related to the improved blast resistance of structures. In its 2000 report, the committee also noted that government support for fortification-related research at universities had declined since the early 1980s, with the predictable result that academic involvement had decreased as well (NRC, 2000).

The committee does not believe that the full potential of U.S. research universities will be realized unless funding is made available to both advance the state of knowledge and contribute to technology transfer. During the Cold War, federal funding for research on blast-related topics and fortification technology was instrumental in developing both an academic research infrastructure and a cadre of qualified research and teaching faculty. Additional research and training opportunities for U.S. universities exist in such fields as injury epidemiology, emergency preparedness, disaster recovery, multihazard mitigation, and decision support. The committee believes that the Blast Mitigation for Structures Program should align itself with other potential sponsors to support university programs in these areas in addition to the more traditional topics of structural and blast-effects engineering.

A STRATEGY FOR THE BLAST MITIGATION FOR STRUCTURES PROGRAM

There are three elements in the technology transfer process for the Blast Mitigation for Structures Program. The committee believes that the first—identification of the information and technology for which there is the most need and that would be of the most value—has been accomplished to a large degree through its workshop, "Protecting People and Buildings from Bomb Damage." The second is the determination of the best venue for dissemination of various types of information to multiple stakeholder groups. The third and broader element is articulation of the appropriate role of a defense support agency such as DTRA in facilitating technology transfer, particularly to the civilian sector.

Venues for Dissemination of Information

The Blast Mitigation for Structures Program is supporting research in many areas, including structural systems, structural and nonstructural components, retrofit materials and techniques, computational modeling, and the distinct but related area of health and injury effects. Although a single approach to technology transfer will not be appropriate for all of the areas under investigation by the Blast Mitigation for Structures Program, the committee believes that knowledge diffusion in building research is sufficiently mature so that successful paradigms for translating Blast Mitigation for Structures Program research into practice exist and can be readily modified to meet the specific needs of the program. The committee also notes the substantial work that has been done on the epidemiology of earthquake-related injuries and believes that it could serve as a valuable model for technology transfer to reduce blast-related injuries.

Earthquakes provide perhaps the closest analog for blast loads on buildings, and earthquake engineering offers the best example of a "lessons learned" program that could serve as a guide for the Blast Mitigation for Structures Program. Following several devastating earthquakes in the 1960s and 1970s, and the appropriation of substantial government funds, U.S. universities and other research facilities began concentrated research efforts to identify and quantify the forces acting on structures and their components during these events and devising design approaches and solutions for addressing them. Over the past 30 years these activities have spawned a vibrant and dynamic infrastructure for both generating new knowledge and translating it into practice.

Through the active collaboration of universities, government agencies, and professional groups, earthquake engineering research in the United States has made great strides toward increasing the understanding of these events, their effects on building structure and nonstructural components, and design and construction methods to mitigate their impact. Engineering research in this area has found its way into practice sooner than has traditionally been the case because code development bodies have maintained close and productive links with the research community. Several government agencies, notably the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST), and the U.S. Geological Survey, have been legislatively designated to conduct or sponsor research and to support the development and publication of design guides and other tools. These efforts are continuing with the establishment of the NSF Network for Earthquake Engineering Simulation, an $81.9 million effort to improve testing equipment and link research results through a high-performance Internet network.

Traditionally, structural research results have been disseminated in a number of ways—in published papers and in lectures; through participation in conferences, code committees, and other activities of professional societies and organizations; and by the sharing of methods and software (McGuire, 1995). Increasingly, research results are also posted to the Internet on industry, university, or organizational Web pages. The Web page of the Blast Mitigation Action Group, under the auspices of the Blast Mitigation for Structures Program, is a limited tool for disseminating product test information (BMAG, 2000). The improvements in engineering design developed through research and testing have ultimately been incorporated into practice, albeit rather slowly, through inclusion in one or more building code documents published by technical or professional societies such as the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), and the American Society of Civil Engineers (ASCE). These documents, together with their accompanying commentary, provide a well-accepted process for subjecting research results to peer review by practitioners and, after they are found credible, a ready conduit for moving the results into practice. The committee believes that code addenda and commentaries would also be an ideal vehicle for making blast-effects mitigation techniques (and their rationale) readily available to the design engineer.

A reason that this process often takes far longer than seems necessary is the different professional venues of researchers and practitioners and the absence in most research proposals of plans and funding for dissemination. On a positive note, evidence suggests that when research has been directly coupled with knowledge dissemination, such as in the earthquake engineering field, the results have been adopted into practice fairly quickly (Roeder, 1995). Although federally supported research efforts cannot contribute directly to the writing of design standards, such efforts can analyze, organize, and present results in a format suitable for ready review and adoption by standards organizations (Noland and Kingsley, 1995). For example, the seismic standards promulgated by FEMA for new construction and structural rehabilitation were developed using this model (FEMA, 1997).

Problems of venue are further compounded by the fact that researchers and practitioners from the defense-oriented blast effects community do not necessarily participate in the same professional events as do architects and engineers from the commercial sector. For example, much interesting work in blast effects and protective design is reported at the biennial "International Symposium on Interaction of the Effects of Munitions with Structures," an event sponsored jointly by DTRA and the German military. Although attendance at most symposium sessions is open to all, some sessions are restricted, and in any event, attendance outside the defense community has traditionally been minimal. Similar conditions prevail at the annual "Shock and Vibration Symposium" sponsored by the Shock and Vibration Information Analysis Center (SAVIAC). Both research results and applications are reported, but typically by members of the defense engineering establishment to others of similar background.

There is some evidence that this situation is improving, however. For example, the "2001 Structures Congress and Exposition" sponsored several sessions on blast effects and blast-resistant design, and the American Concrete Institute and American Institute of Steel Construction are including blast-related sessions in their annual conference programs. Although the committee views these as favorable developments, such activities will not, absent other proactive efforts, resolve the issue of bringing together the research and practitioner communities for the exchange of concerns, needs, solutions, applications, and deployment strategies. This is especially important given the multidisciplinary aspects of blast-effects mitigation.

As was so amply demonstrated by the committee's workshop, "Protecting People and Buildings from Bomb Damage," it is necessary not only to bring together engineers engaged in research and practice, but also to involve architects, builders, and emergency service providers as well. The role of the architect/engineer, in particular, cannot be overemphasized in the practical diffusion of new knowledge and approaches. Interaction with the client/owner in a building project most often occurs through the architect/engineer, and it is often left to the architect/engineer to explain the design philosophy inherent in blast-resistant construction, its potential multihazard benefits, and cost tradeoffs. Obviously, to play this role, the architect/engineer must accept blast mitigation as a design parameter or program requirement, be well versed in all aspects of the field, and have the necessary informational resources available. This range of capabilities has certainly become the norm in seismic design and rehabilitation (California Seismic Safety Commission, 1992).

In its earlier report, the committee noted that the Blast Mitigation for Structures Program should consider sponsoring an annual or biennial conference on blast-mitigation design and engineering (NRC, 2000). Despite the fact that these issues are discussed at existing engineering, construction, security, and emergency management conferences, the committee now believes even more strongly that a single, integrated, multidisciplinary event would be of enormous benefit in the dissemination of the latest advances in blast-resistant design and construction, could stimulate the development of new and effective retrofitting concepts for existing structures, and could promote desirable interactions among all involved stakeholder communities. For example, the Blast Mitigation for Structures Program is sponsoring the development of computer models to predict blast-related injuries to persons from glazing, nonstructural building components, and office equipment. The committee believes that both the program and the emergency medical community would benefit from an ongoing dialogue regarding the analytical approach, data needs, and field observations from other bombing events as well as severe earthquakes. However, no such dialogue is occurring.

Another potentially valuable opportunity for stimulating productive communication among stakeholders arises from the "Symposium on Secu-

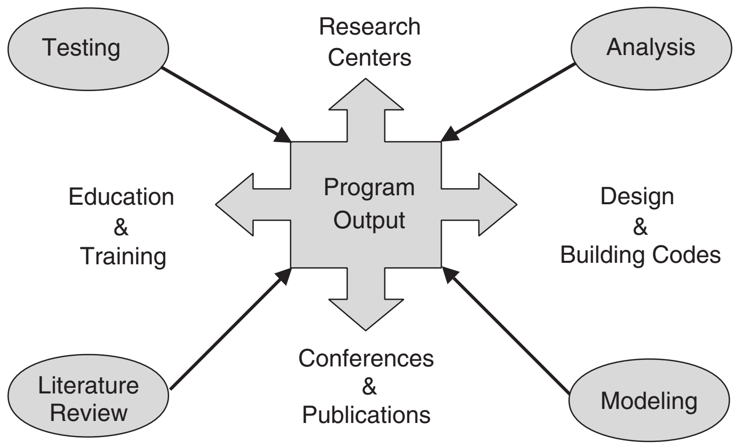

FIGURE 3.1 Overall strategy for technology transfer for the Blast Mitigation for Structures Program.

rity and Openness in Federal Architecture" sponsored in 1999 by the General Services Administration and the Department of State. The dominant theme of the symposium was the question of whether security considerations inherently meant fortress or bunker-type buildings or otherwise precluded good design. Contributors to the Blast Mitigation for Structures Program could provide valuable guidance to architects and to the landscape architecture and site design professions through papers, presentations, and workshops delivered at professional conferences and other gatherings of these groups. Again, the committee does not believe that these interactions currently occur at a rate sufficient to satisfy the demand for information.

Figure 3.1 depicts elements of a comprehensive technology transfer strategy for the Blast Mitigation for Structures Program. Table 3.1 identifies target stakeholder groups for the various products that the technology transfer effort could yield.

Risk Management for Multiple Hazards

Experience over the past decade has shown that while attacks against buildings and their occupants utilizing large, vehicle-bombs have been infrequent, hundreds of smaller bombing attacks against buildings do occur (FBI, 1998). However, given the large inventory of buildings potentially at risk, the probability of an attack against a specific building is quite low. The magnitude of the threat and the likelihood of an attack against a specific building depend on the building's mission and location and will vary con-

TABLE 3.1 A Technology Transfer Framework for Blast-effects Mitigation

Activity/ Product	Focus	Target Audience: Academia	Design Practitioners	Public Policy Makers	Owners, Users, and Other Groups	Informed Lay People
Technical reports	Blast Mitigation for Structures Program research topics	X	X	X		
Engineering applications	Blast Mitigation for Structures Program research and test results	X	X		X	
Newsletters/ Internet postings	Blast Mitigation for Structures Program research updates, activities	X	X	X	X	
Workshops	State-of-knowledge exchange	X	X			
Conferences	Review, application of research	X	X	X		
Seminars, briefings	Current issues of technical interest	X	X	X	X	
Short courses	Professionally relevant research and applications	X	X	X		
Owner/ public awareness	Hazard and risk education; design philosophy	X	X	X	X	X
Computer programs	Design analysis, vulnerability assessments	X	X			

SOURCE: After Lee and Dargush (1995).

siderably. Protective design guidelines are intended to be applicable to a wide range of buildings and facilities constructed in various locations, both domestically and overseas. These buildings vary in use from general-purpose office buildings, to personnel quarters, to maintenance facilities. Depending on their geographic location, they will also be faced with a wide range of natural hazards, including earthquakes, extreme wind events, landslides, and floods. Each facility will have a unique set of mission objectives, design considerations, site characteristics, threat profiles and risk tolerance, and budgetary limitations. Under these circumstances, it is impractical, and certainly inefficient, to prescribe the same uniform set of security requirements for all buildings at all locations. Determining what security and hazard mitigation measures are necessary and acceptable should be done on a case-by-case basis and be the consensus outcome of an interactive planning and programming process.

The committee recognizes that the principles of security engineering, defensive planning and architecture, and blast-effects and natural hazard mitigation are well known to those routinely involved with these matters. However, as the committee's recent workshop made clear, the process of planning and programming new facilities involves many individuals who lack such specialized knowledge. During the building planning process, a range of functional issues must be addressed. For example, if assets of special value (e.g., critical infrastructure elements, mainframe computer installations, communications, vital records, or back-up data) are to be housed in the building, any required blast mitigation or other security provisions have to be identified in the beginning stages of the design process, and not as an issue after the fact. Damage to critical equipment represents a serious capital loss and could compromise the facility's mission as well. During the planning phase, it should be recognized and discussed that "least-cost" construction may compromise desired structural and operational performance. Essentially a one-way process, traditional facility delivery provides little opportunity to revisit initial assumptions, verify the acceptability of changes made during subsequent steps in the process, and benefit from the synergy of a fully integrated project delivery team.

The delivery process for all facilities that could be the target of a terrorist attack, as well as buildings subject to natural hazards, should have as its goal the identification and successful management of risk factors that can adversely affect facility performance. Investigations of performance failure, whether structural or with respect to user expectations for a facility, have usually determined that most failures are preventable. Many failures can be traced, at least in part, to poor communication between individual elements of the project delivery system and to the fact that each building is one of a kind, presenting no real opportunity to test prototypes as in a mass production process. Shortcomings in communication are magnified in the traditional design and construction process, which is compartmentalized and tends to inhibit free and interactive exchanges between elements and across disciplines. Because many security and natural hazard issues, and approaches to mitigating them, are introduced at different steps in the facility delivery process, having a process flexible enough to integrate them with the facility's primary mission is important. Although risk will always be a factor with facilities presenting security and natural hazard concerns, better systems can be designed to both reduce the overall level of risk and manage the residual risk more effectively, particularly if the issue of risk is presented in a format that is understandable to individuals of diverse backgrounds. The committee believes that the Blast Mitigation for Structures Program should give some consideration to supporting the development of a performance-based design process that integrates security and natural hazard mitigation objectives with new technologies and risk management principles as shown in Figure 3.2.

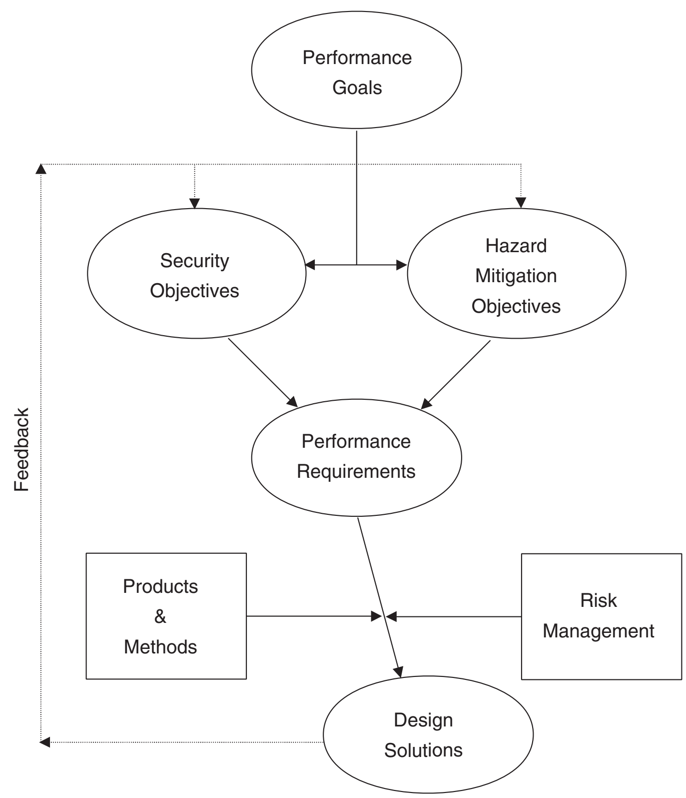

FIGURE 3.2 A performance-based multihazard mitigation model.

The Role of the Defense Threat Reduction Agency

As a technical support agency of the Department of Defense, DTRA (and its predecessors, the Armed Forces Special Weapons Project, the Defense Atomic Support Agency, and the Defense Nuclear Agency) has traditionally developed blast-effects information, with responsibility for dissemination falling primarily to the Army, Navy, and Air Force through the publication of technical manuals and design guides. The Defense Nuclear Agency sponsored much of the early work on the response of structures to nuclear blast effects. This research, although primarily oriented to the national defense, contributed significantly to the understanding of soil-structure interaction and the development of first-principles computer modeling techniques that underpin the seismic design of buildings. Today, the stated mission of DTRA is ". . . to safeguard America and its friends from weapons of mass destruction (chemical, biological, radiological, nuclear, and high explosives) by reducing the present threat and preparing for the future threat" (DTRA, 2001). At the committee's workshop, Dr. Jay Davis, director of DTRA, underscored DTRA's mission in his keynote address (see Appendix C) when he said:

> We are conducting a program focused on the needs of the Department of Defense. Although I cannot fund a civil research program, it will be scandalous if we don't expand that program to deal with any possible civil questions that we can. My charge to you is that the civil design and building community needs to understand what we do in such a way that you can help us find some of those synergies, because we won't find them all.

Despite the fact that DTRA has had little direct responsibility for civil matters within the United States, the committee believes that transferring the results of the Blast Mitigation for Structures Program to the civilian sector is in full accord with the DTRA mission and that the Blast Mitigation for Structures Program is also in an excellent position to facilitate Dr. Davis's charge to the workshop attendees.

The Department of Defense is also a member of the Interagency Security Committee that was established by Executive Order 12977 (Clinton, 1995) and has been charged, among other tasks, to:

> (3) take such actions as may be necessary to enhance the quality and effectiveness of security and protection of Federal facilities, including but not limited to:
>
> (A) encouraging agencies with security responsibilities to share security-related intelligence in a timely and cooperative manner;
> (B) assessing technology and information systems as a means of

providing cost-effective improvements to security in Federal facilities;

(C) developing long-term construction standards for those locations with threat levels or missions that require blast resistant structures or other specialized security requirements;

(D) evaluating standards for the location of, and special security related to, day care centers in Federal facilities; and

(E) assisting the Administrator in developing and maintaining a centralized security data base of all Federal facilities.

The committee believes that the results of the Blast Mitigation for Structures Program should be made available to the Interagency Security Committee (and its member agencies) so that it can carry out the charge embodied in Executive Order 12977.

The successes of earthquake engineering in the United States that have led to improvements in new construction and rehabilitated existing buildings are grounded in both the high quality of the research and the ready availability of institutional infrastructure to move it into practice. While funding for blast-effects mitigation will probably never approach the levels expended for improving seismic performance, the committee believes that the Blast Mitigation for Structures Program, with only slight reallocations of funding, could begin to establish a technology transfer infrastructure that would serve to disseminate the body of knowledge already created as well as future developments in the field. The committee noted this in its earlier report:

> **Conclusion 10.** The barriers to the complete and effective transfer of the results of the BMSP will require considerable time and effort to overcome. A convenient way to reduce the transfer time would be to use existing institutional infrastructures (i.e., building code and standards-writing organizations, professional and technical organizations, universities, and research centers) to disseminate knowledge. (NRC, 2000)

However, the committee believes that if real and lasting progress in this area is to be achieved, there will have to be sustained funding for both continued research and technology transfer activities.

The role envisioned for DTRA in this activity is twofold. First, as the primary sponsor of ongoing research, DTRA will have to continue in its present mode of identifying knowledge gaps, establishing priorities, and guiding the conduct and output of the research effort. Second, DTRA will have to establish working agreements and memoranda of understanding, and formalize other arrangements with government and private sector partners and technical and professional organizations. The purpose of these agreements would be to institutionalize relationships and establish roles and responsibilities for those organizations involved in the technology transfer effort. For example, the AIA, ACI, AISC, ASCE, and ASME all have an interest in blast-effects mitigation and all are involved in code-writing activities. What is absent from the technology transfer model that has proved successful for earthquake engineering is a mechanism for these groups to actively influence the content and conduct of the research program, identify gaps and overlaps, and link the research results with ongoing code development activities within their respective organizations.

The Blast Mitigation for Structures Program has developed a working relationship with the AISC Committee for the Design of Blast Resistant Buildings. Although no formal relationship exists, this activity could lead to the type of interactive relationship that the committee believes is critical to the long-term success and legacy of the program. Another example from earthquake engineering practice of the benefits of collaboration is the development of the *National Earthquake Hazards Reduction Program Guidelines for Seismic Rehabilitation of Buildings and Commentary* (FEMA, 1997). The Building Seismic Safety Council of the National Institute of Building Sciences, under contract to FEMA, retained the Applied Technology Council and the American Society of Civil Engineers as technical consultants to produce what has become the national standard for seismic rehabilitation of existing buildings.

Organizations such as the Applied Technology Council have participated in many technology transfer and information dissemination activities that have been instrumental in advancing the practice of earthquake engineering and post-earthquake operations. Their involvement has included providing the technical basis for the seismic provisions in the current Uniform Building Code, methods for assessing earthquake damage and loss estimation that have been widely used for earthquake insurance portfolio analysis, and standard methods for determining if damaged buildings can be safely occupied. These documents have been widely accepted by practicing design professionals in the private sector.

Numerous information clearinghouses compile, organize, and disseminate information on various topics on behalf of government agencies. They are increasingly Web-based and usually have quite powerful directed search capabilities. The Department of Defense originated the Information Analysis Center to serve in this capacity for technical activities of interest to DoD and its many ancillary organizations. SAVIAC, the Shock and Vibration Information Analysis Center, and DTRIAC, DTRA's Nuclear Weapons Effects Information Analysis Center, have addressed blast-effects and protective design issues and could potentially serve as a clearinghouse for products of the Blast Mitigation for Structures Program and other blast-related information. If desired, a clearinghouse on the model of the information analysis center could be structured to provide several classes of access ranging from unrestricted distribution to classified. This type of layered security architecture could address some of the questions that are raised in the next section regarding the handling of potentially sensitive information.

Although the details will differ from application to application, the committee believes that there are sufficient and adequate models to serve as examples of what DTRA could accomplish in the transfer of blast-resistant technology. Similar efforts should be cultivated with other groups that have an interest in blast-effects mitigation.

Security Issues

Although earthquakes and extreme wind events may have effects analogous to blast loadings in certain respects, they are natural events, not malevolent acts. It is not possible to alter their timing or path to maximize the damage inflicted on persons and property—precisely the objective of terrorist bombers. The committee believes that the potential for deliberate, planned infliction of devastating damage is an aspect of the technology transfer question that must be openly discussed and resolved before there can be any meaningful dissemination of the results of the Blast Mitigation for Structures Program to the private sector.

The primary objection raised to widespread dissemination of the results of the Blast Mitigation for Structures Program is that some of the information would be of value to terrorists in planning and carrying out future attacks. The committee agrees that some of the results of the Blast Mitigation for Structures Program (as well as other information in existing military and government manuals) are potentially sensitive in this regard. For example, certain test data concerning the performance of columns or other structural components subjected to a bomb of a given size at a specific standoff distance would be valuable to a terrorist. Similarly, the design basis (underlying assumptions of design blast loads and the location and configuration of critical services) for a specific building would be invaluable to terrorists planning an attack. Also of concern are the various damage assessment programs, planning tools, and injury-prediction models that either already exist or are being produced as a result of the Blast Mitigation for Structures Program. These computerized models permit the rapid comparison of attack scenarios for the purpose of devising and testing defensive strategies. In the wrong hands, they could compromise security and aid terrorists.

Overall, however, the committee believes that knowledge diffusion and information sharing on generalized design approaches to mitigate blast effects (such as discussed in this report) would generate considerable benefit and very little harm. (No need has been seen, for example, to restrict access to fire resistance ratings or the design of fire suppression systems out of fear that the information will be of use to arsonists.) Discussions at the workshop focused on the needs of architects and engineers in the private sector for tools to aid the planning and design process, rather than damage assessment. The committee believes that the Blast Mitigation for Structures Program is in an excellent position to provide the type of design guidance needed without compromising sensitive information that could aid terrorists. It is the committee's considered opinion that it would be shortsighted in the extreme for a government program to develop a body of knowledge that could save lives, reduce injuries, and mitigate property damage, and then withhold this knowledge from broad public access.

The committee also believes that current limitations on the availability of existing government manuals are unduly restrictive. There are excellent documents produced by the military (e.g., *Design and Analysis of Hardened Structures to Conventional Weapons Effects* [U.S. Army et al., 1997] and *Security Engineering* [U.S. Army, 1993]) that could address (perhaps with some information deleted or restated) many of the questions raised by private-sector stakeholders at the committee's workshop. However, these documents can be distributed to "U.S. Government agencies and their contractors only" or carry "Official Use Only" designations that limit their availability to a small group of architects and engineers—a practice viewed by the committee as a major barrier to effective technology transfer. The committee strongly supports the ongoing efforts of the Blast Mitigation for Structures Program to maximize public availability of all but the most sensitive test data and design assumptions and notes that *Structures to Resist the Effects of Accidental Explosions* (U.S. Army, 1990), a widely used and valuable reference, is currently listed for "Unlimited Distribution."

The committee offers the following two examples of valuable technology transfer products that would couple existing design approaches with new information developed by the Blast Mitigation for Structures Program and would have no negative security impacts.

1. At the workshop there was considerable discussion of the need for simplified procedures for identifying and estimating the cost of blast-resistant features for commercial construction, particularly specific products that meet a performance specification. Security Engineering Manual TM 5-853 (U.S. Army, 1993) contains just such simplified procedures for selecting glazing, walls, and other components based on an assumed weight of explosive and standoff distance. However, TM 5-853 is restricted to "Official Use Only"—use by government agencies and their contractors—and also does not identify specific products that satisfy design conditions. The committee believes that a guide with unrestricted distri-

bution and modeled on the Security Engineering Manual approach would be an excellent product for the Blast Mitigation for Structures Program to develop. It would enable architects and engineers, in concert with their clients, to identify possible threat scenarios, design solutions, and products that have been shown by testing to satisfy their assumed design conditions.

2. Another example of a guidance document that the committee believes would find widespread acceptance is a guide for decreasing the injury potential of interior spaces subject to blast energy. The Blast Mitigation for Structures Program has tested numerous office configurations and methods of restricting the movement of nonstructural elements such as furniture, overhead fixtures, and office equipment. There has also been a good deal published on how to address this issue in buildings subject to earthquake. It would be a relatively simple matter to combine the guidance already available for earthquake protection with the empirical results of the Blast Mitigation for Structures Program and produce a straightforward, practical guide that could be useful to the military as well as civilian government agencies and the private sector.

Additional products that the committee believes would support the widespread dissemination of blast mitigation guidance include:

- Research summaries with a view to implementation in practice and results of tests that have demonstrated blast-resistant design methods for both new construction and retrofit conditions,
- Reports on the cost impact of varying levels of blast resistance for new and retrofit construction for different classes of buildings, and
- Reports on the importance of providing safety against blast similar to existing reports on protection against earthquakes.

SUMMARY

The Blast Mitigation for Structures Program offers a great opportunity to save lives and reduce injuries in the event of a terrorist bombing. The full benefits of the program will be realized, however, only if the results are widely disseminated and necessary improvements implemented. The process described by the committee would use existing institutional infrastructure (i.e., building code and standards-writing organizations, professional and technical organizations, universities, and research centers) to disseminate knowledge. Technology transfer for this purpose falls within DTRA's mission and the Blast Mitigation for Structures Program could readily adapt the model already developed and used by the earthquake engineering community. Issues exist regarding the security of sensitive information, but the committee believes that they are resolvable and should not become an impediment to the effective and timely transfer of information.

Widespread implementation of blast-resistant construction, however, presents a more formidable issue—particularly for the private sector. All building decisions, whether in the public or private sector, are strongly influenced by cost in relation to the marketplace. Discussions at the committee's workshop confirmed that most commercial building owners view the threat from terrorist bombing as minimal for normal commercial occupancies. Consequently, there is little incentive on the owner's part to authorize any additional funds for blast resistance. Blast-resistant construction, however, can also provide protection against natural hazards such as earthquakes and extreme wind events, for which there are building code requirements. Features typically added to improve blast resistance, such as reinforcing splices that increase ductility, impact-resistant glazing, and restraints on nonstructural elements, will improve building performance during earthquakes and extreme wind events as well. As part of a *multihazard* mitigation strategy, improved blast resistance may add only a marginal cost, or even no cost.

An even stronger case can be made for applying blast-resistant features to existing buildings. A significant cost of seismic retrofit, for example, is preparing the structure for rehabilitation, and this would present an excellent opportunity to add blast-resistant features at the same time. In fact, many seismic retrofit techniques such as wrapping concrete columns with carbon fiber material or securing fixtures and appurtenances to prevent them from causing injury are essentially the same as techniques for improving blast resistance. An important element of the Blast Mitigation for Structures Program technology transfer strategy should be to identify and highlight any common approaches that address a broad range of hazards. In this way, cost barriers to achieving improved blast resistance can be reduced.

Discussions at the November 2000 workshop were quite clear in emphasizing that more information should be made available to the nonspecialist in blast engineering. The committee believes that dissemination of up-to-date information is needed at all levels so that architects, engineers, and owners can be more informed in their general advice, approaches to design, and owner decision making. The committee recognizes buildings as systems of their components and knows that no decision affecting performance is trivial. Thus, it does not intend to imply that a design decision for a blast-resistant door, for example, is less important than that affecting the structural frame. However, the project architect or engineer who designs a building that presents little risk of being attacked should possess enough knowledge of the issues to be able to discuss options intelligently with the owner and identify the need (if any) for a more knowledgeable blast consultant. The committee believes that if information is made broadly available, professional ethics and individual responsibility should provide adequate control over its appropriate application in practice.

Overall, the committee believes that the key to effective technology transfer for improved blast resistance is commitment to the process. The knowledge base either exists or can be developed. Applying it effectively will require continuous interaction between the various stakeholders to exchange information on needs, approaches, and solutions. The infrastructure for these interactions also exists and can be adapted to the needs of the Blast Mitigation for Structures Program. What is required, and strongly recommended by the committee, is the necessary commitment of time and resources by DTRA and other relevant agencies to enable technology transfer for mitigation of blast effects. Without such a commitment the committee is concerned that a unique opportunity to reap the benefits of valuable and costly research will be lost.

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*Distribution of this document is restricted to U.S. government agencies and their contractors, and the document may not be readily available to the general public.

4

Conclusions and Recommendations

CONCLUSIONS

The committee reached the following conclusions regarding what it believes are the most pressing and fundamental questions related to the dissemination of blast-effects information.

1. In light of world conditions, as amplified by the events of September 11, 2001, that suggest a continuing terrorist threat to the United States and its citizens, the engineering and architectural professions have an ongoing need for blast-effects design guidance.
2. Promoting technology transfer of the results of the Blast Mitigation for Structures Program falls within the mission of the Defense Threat Reduction Agency to ". . . safeguard America and its friends from weapons of mass destruction."
3. DTRA has tended to focus on military applications of the outputs of the Blast Mitigation for Structures Program, but the committee believes that to achieve maximum effectiveness in realizing the goal of "protecting people in buildings," the results of the program should be targeted to nondefense government agencies and the civilian design and building community, i.e., the nonspecialists in protective design.
4. Because interaction with the client/owner in a civilian building project most often occurs through the architect/engineer—and it is often left to the architect/engineer to explain the design philosophy

inherent in blast-resistant construction, its potential multihazard benefits, and cost tradeoffs—architects/engineers have a critical role to play in the practical diffusion of new knowledge and approaches for blast-effects mitigation.

5. The requisite level of knowledge will vary depending on the role of the engineer or architect in an individual project and the nature of that project. However, at a minimum, all building design professionals involved with buildings potentially subject to blast effects should be familiar with how structures are affected by explosions (loading and response of structural and nonstructural systems), blast-effects mitigation measures, and basic life safety considerations. Specific design problems may require higher levels of knowledge and some may be addressed only by a specialized blast engineer. This should not be construed to imply that all blast problems are the province of the specialist; qualified design professionals properly guided by up-to-date information can adequately address many blast-related issues.
6. Engineers and architects involved with blast-resistant design require information that will allow them to translate security objectives for a given facility into performance requirements for the building and site. Performance requirements must be the product of a multiobjective decision process that includes risk and cost factors. Essential to developing design solutions that will achieve the performance requirements is knowledge of such varied topics as, for example, the purpose and value of standoff;[1] the effectiveness of vehicle barriers and other methods for screening the building, its entrances and exits, and its occupants from potential attackers; the performance of reinforcement splices, column wrappings, and other structural retrofit methods; the performance of glazing materials, window systems, vents, and doors; the design, selection, and arrangement of interior, nonstructural features such as furniture, office equipment, and overhead fixtures, to prevent them from becoming agents of additional damage or injury; and the means of facilitating the rescue of the building's occupants in the event of an attack. There is also a need for simplified design guidance for lesser hardening and moderate hardening levels of blast-resistant design.
7. Information sources can and should take many forms. These will include published conference papers, technical letters and manuals,

[1]Standoff is generally understood to be the distance between the detonation point of a bomb and the target building.

Web pages, workshops, symposia, and short courses. Technology transfer is an ongoing process; to be successful it must be continuously evaluated and updated to match the needs of the user with the capabilities of emerging technology. Both will evolve over time.

8. Significant work in structural systems and materials that has been underway for many years in U.S. research universities could advance the objectives of the Blast Mitigation for Structures Program, but the program has not taken full advantage of these capabilities.
9. The private sector is much more cost sensitive than the military or civilian federal sectors. Cost and market demands are very likely to determine what, if anything, is done to protect commercial buildings and their occupants from bombing attacks. In the committee's judgment, the cost sensitivity of the private sector can best be addressed by a multihazard approach to blast-effects mitigation, particularly in the case of building retrofits, that will provide collateral protection against other hazards such as earthquakes, extreme wind events, fire, and flood.
10. There is a need to develop a decision framework that will permit military installations, government agencies, and commercial building owners to implement necessary security and blast- and natural hazard-mitigation practices based on a balanced assessment of threats, building vulnerabilities, acceptable risks, and available resources. This framework should include accurate and up-to-date cost-estimating information for various levels of protection that can be applied to both new and retrofit construction.
11. With appropriate precautions, the design guidance for blast-effects mitigation that would be most useful to the engineering and architectural communities can be disseminated in a form that will not compromise sensitive information and aid terrorists.

RECOMMENDATIONS

The committee believes that the Defense Threat Reduction Agency (DTRA) is uniquely positioned to make its mission objective of "protecting people in buildings" a reality. The agency has carried out a focused and valuable program of research and testing, engineering analysis, and computational modeling to supplement a formidable body of existing knowledge on blast effects and blast-resistant construction. Although much work still remains to be done, much of value has already been completed. However, the full benefits of this effort will be realized only if the technology is *implemented,* and this requires that the information developed be made broadly available to all those in a position to utilize it. For this reason, the committee offers the following recommendations for technology transfer of the results of the Blast Mitigation for Structures Program.

1. DTRA should take a leadership position in facilitating the implementation of the comprehensive technology transfer strategy articulated throughout this report. This includes the development and dissemination (for unrestricted release) of specific products (e.g., design and cost-estimating guides, assessment tools, databases); encouragement of the presentation and publication of research results and potential applications in mainstream civilian (as opposed to defense-oriented) engineering and architectural conferences and journals; support of venues for the meeting and interaction of researchers and practitioners such as technical committees, conference sessions, symposia, and workshops; support of a product database of materials linked to blast performance specifications; and maintenance of outreach services through print or Web-based newsletters. The committee believes that technology transfer is an integral component of the Blast Mitigation for Structures Program and that sufficient funds should be set aside by DTRA or others to establish and sustain the effort.
2. DTRA should contract with an organization familiar with technology transfer to manage the activity on DTRA's behalf. Organizations that have performed similar functions include the Applied Technology Council (earthquake and wind engineering), DoD information analysis centers such as the Shock and Vibration Information Analysis Center (SAVIAC) and DTRA's Nuclear Weapons Effects Information Analysis Center (DTRIAC), and several private contractors that operate information clearinghouses for government programs. The Construction Criteria Base (CCB) is published quarterly on CD-ROM by the National Institute of Building Sciences and contains construction-related documents from 22 federal agencies and 110 industry organizations. The CCB may be useful in making blast-mitigation technology available to a wide audience of design professionals.
3. The Blast Mitigation for Structures Program should survey and evaluate relevant ongoing university research with the objective of identifying and synthesizing what may be of value for improving the performance of buildings in a blast environment and also consider universities for direct participation in the research effort.
4. The Blast Mitigation for Structures Program technology transfer effort should emphasize techniques and products for the retrofit of existing buildings and take advantage of the opportunities thus presented to achieve protection against multiple hazards such as

earthquakes, extreme wind events, fire, and flood, as well as blast effects.

5. Implementation of blast mitigation measures should be based on established risk management principles. The Blast Mitigation for Structures Program should develop a performance-based, multi-objective design process for federal facilities that integrates security and natural hazard mitigation objectives with new technologies and is based on building mission, defined threat, acceptable risk, and available resources.
6. To gather valuable and perishable medical data, the Blast Mitigation for Structures Program should support the establishment within an appropriate agency (e.g., Centers for Disease Control and Prevention, FEMA, Bureau of Alcohol, Tobacco, and Firearms) of rapid response data-gathering teams to investigate bombing attacks that may occur in the future. The data collected by these teams should be integrated with information from past events and made available to researchers and practitioners in emergency medicine, injury epidemiology, search and rescue, architecture, and engineering.
7. DTRA should establish an interagency committee composed of both military and civilian members to provide customer input on the content and conduct of the technology transfer effort. Alternatively, DTRA could make use of the Physical Security and Hazard Mitigation Committee recently established by the Federal Facilities Council of the National Research Council to provide this service. The committee believes that it is important to establish and maintain a forum for customers and potential customers of the Blast Mitigation for Structures Program (such as the newly established Office of National Preparedness at FEMA) to provide feedback to both the research and the technology transfer components of the program.

Appendixes

A

Biographies of Committee Members

Mete A. Sozen (Chair), NAE, is the Kettelhut Distinguished Professor of Structural Engineering at Purdue University. Dr. Sozen specializes in teaching and research related to the analysis and design of concrete structures subject to earthquake and other dynamic loadings. He is the recipient of many awards and honors, including the Lindau Award and Kelly Award, American Concrete Institute (ACI); Boase Award, Reinforced Concrete Council; Research Prize, Howard Award, and R.C. Reese Award, American Society of Civil Engineers (ASCE); General Electric Senior Research Award of the ASCE; Lifetime Achievement Award of the Illinois Section of ASCE; the Parlar Science Award of Middle East Technical University (Turkey); and election to the Royal Swedish Academy of Engineering Sciences. He is an honorary member of the Association of Turkish Engineers, ASCE, and the ACI. He has served as a member of the Veterans Administration Advisory Committee on Structural Safety; ACI Technical Activities Committee; ACI Committee 318 on the Building Code; and chair of the United States-Japan Cooperative Research Program on Urban Earthquake Hazard Reduction. In 1996, he participated in the Federal Emergency Management Agency's Building Performance Assessment Team's investigation of the Oklahoma City bombing. Dr. Sozen has served as the chair of the National Research Council Committee on Natural Disasters and Committee on Earthquake Engineering. He holds honorary doctorates from Bogazici University (Turkey) and Janusz Pannonious University (Hungary) and has earned a B.S. in civil engineering from Robert College, and an M.S. and

Ph.D. in civil engineering from the University of Illinois at Champaign-Urbana.

Stephen W. Attaway is a distinguished member of the technical staff at Sandia National Laboratories. His expertise is in computational simulation and modeling and code development for applications in solid mechanics. Dr. Attaway is currently leading research and development for the development of solid mechanics code at Sandia's Engineering Science Center, including the development of coupled codes for blast-structure interaction. He received his B.S., M.S., and Ph.D. degrees in civil engineering, all from the Georgia Institute of Technology.

Erik Auf der Heide is a medical officer with the Agency for Toxic Substances and Disease Registry of the U.S. Department of Health and Human Services. He is also an adjunct assistant professor in emergency medicine at the Emory University School of Medicine, where he completed a fellowship in disaster medicine. He is the author of two textbooks and a number of articles on disaster management. Dr. Auf der Heide is a member of the Disaster Section of the American College of Emergency Physicians. He received his M.D. from Baylor College of Medicine and an M.P.H. in epidemiology from the Rollins School of Public Health, Emory University School of Medicine, and he is certified by the American Board of Emergency Medicine.

W. Gene Corley, NAE, is vice president of Construction Technology Laboratories. His expertise is in structural concrete for earthquake-resistant construction, the uses of concrete in buildings and bridges, investigations of structural failure, and building codes. Dr. Corley serves on the Technical Council on Forensic Engineering of the American Society of Civil Engineers and was the principal investigator on the Building Performance Assessment Team dispatched by the Federal Emergency Management Agency to study the Alfred P. Murrah Federal Building in the aftermath of the bombing. He received his B.S. and M.S. in civil engineering and his Ph.D. in structural engineering from the University of Illinois at Champaign-Urbana.

Eve Hinman, principal of Hinman Consulting Engineers, has experience in the design and analysis of structures subject to the effects of explosions and project experience in the effects of conventional and nuclear weapons, accidental explosions, and terrorist attack. She has provided consultant services to the General Services Administration, the U.S. Department of State, and the Port Authority of New York and New Jersey. Dr. Hinman has conducted many investigations of accidental explosions and the bombing of the Alfred P. Murrah Federal Building in Oklahoma City. She has a

B.S. in civil engineering, an M.S. in structural engineering, and a D.Sc. in engineering mechanics, all from Columbia University.

Robert P. Kennedy, NAE, is a consulting engineer in structural mechanics with expertise in structural dynamics, structures, earthquake engineering, engineering mechanics, design codes, and standards. He has experience in static and dynamic analysis and the design of special-purpose civil and mechanical-type structures, particularly for the nuclear, petroleum, and defense industries. He has designed structures to resist extreme loadings, including seismic landings, missile impact, extreme wind, impulsive loads, and nuclear environmental effects, and he has developed computerized structural analysis methods. Dr. Kennedy received his B.S. in civil engineering and his M.S. and Ph.D. in structural engineering from Stanford University.

Sam A. Kiger is chair of the department and the C.W. La Pierre Professor of Civil and Environmental Engineering, and director of the National Center for Explosion Resistant Design (NCERD), at the University of Missouri-Columbia. His areas of expertise are structural analysis and design, structural dynamics, explosion effects, protective construction, and soil-structure interaction. The NCERD is an interdisciplinary center that serves as a national focus for university-based research to create new knowledge and improve understanding of the explosion environment and blast-mitigation technology; create new and improved structural designs and strategies for protection from explosions; and transfer technology through publications, short courses, and university degree programs. Prior to teaching, Dr. Kiger spent many years on the staff of the Waterways Experiment Station of the U.S. Army Corps of Engineers, where much of his work was focused on the effects of explosions on structures. He received his B.S., M.S., and Ph.D. in theoretical and applied mechanics from the University of Illinois at Champaign-Urbana.

Stuart L. Knoop is a registered architect, a fellow of the American Institute of Architects, and co-founder of Oudens and Knoop, Architects, PC, of Chevy Chase, Maryland. He has been involved in design for security for many years, particularly for the U.S. State Department, Office of Foreign Buildings Operations. Oudens and Knoop has designed security upgrades for more than 60 embassies and consulates worldwide. Mr. Knoop has served on the National Research Council (NRC) Committee on Research for the Security of Future U.S. Embassy Buildings and was vice chair of the committee that produced the NRC report *Protecting Buildings from Bomb Damage* (National Academy Press, Washington, D.C., 1995). He is a member of the NRC Division on Engineering and Physical Sciences. Mr. Knoop holds a B.Arch. from Carnegie Institute of Technology.

Johanna LaPierre, associate vice president at RTKL Associates, Inc., has experience in architectural, interior, and landscape architecture on projects ranging from large-scale office developments and renovations to embassies, hotels, and historic restorations. Her responsibilities have included project management and coordination, design, production of contract documents, and contract administration. She has also been a project manager for security upgrades at the U.S. Capitol, U.S. Supreme Court, and Library of Congress, as well as numerous U.S. Department of State facilities worldwide. She holds a B.A. from Cornell College and an M.Arch. from the University of Virginia.

Mark Loizeaux is chairman of the Loizeaux Group of Companies, chief executive officer of Loizeaux Group International, and president of Controlled Demolition, Inc. Mr. Loizeaux has 35 years of experience in both the conventional and explosives demolition trades and provides consulting services on demolition and site clearance, rock removal and vibration control, antiterrorist measures to mitigate the effect of attacks on structures, and forensic analysis of damaged structures to determine the cause of damage. He has been personally responsible for field supervision of the demolition of more than 1,200 structures worldwide and is internationally recognized as a leader in the demolition and explosives industry. Mr. Loizeaux holds a B.S. in business administration from the University of Tennessee.

J.L. Merritt, an independent consulting engineer in civil, geotechnical, and structural engineering, has extensive research and practical experience in the design of protective structures, soil-structure and blast-structure interactions, and earthquake engineering. He has published more than 70 articles, papers, and monographs. Prior to his consulting career he taught at the University of Illinois, where he attained the rank of professor. He is a member of numerous professional societies and a registered engineer in various specialties (civil, geotechnical, and structural) in four states. Dr. Merritt received a B.S. in civil engineering from Lehigh University and an M.S. in civil engineering and a Ph.D. in engineering from the University of Illinois at Champaign-Urbana.

David J. Pelgrim, an engineer with E.K. Fox & Associates Consulting Engineers, has been responsible for the design of numerous physical and technical security upgrade projects, the production of feasibility studies, the performance of field investigations, and the creation of construction documents. He has undertaken projects for numerous clients, including the

U.S. Army Corps of Engineers, the U.S. Navy, the U.S. Air Force, the General Services Administration, the U.S. Department of State, the U.S. Department of Justice, and the District of Columbia. He has completed the design of systems at numerous facilities throughout the world, spanning all physical and technical threat levels. In addition to his work in facility security, Mr. Pelgrim has been engaged in a broad range of projects involving the design of power, lighting, fire protection, life safety, communications, automated controls, and other building systems. He has also been involved in the design of innovative building systems as a joint venture between the General Services Administration's Centers for Expertise and Carnegie Mellon University. Mr. Pelgrim holds a B.S. in mechanical engineering from the University of Maryland at College Park and is a registered professional engineer.

Eugene Sevin, NAE, is an independent consultant. His research interests are nuclear and conventional weapons effects, hardened facility design, and computational structural mechanics. He formerly served with the U.S. Department of Defense (DoD) as deputy director, Space and Missiles Systems, and with the Defense Nuclear Agency as assistant to the deputy director (Science and Technology) for experimental research. Dr. Sevin was professor of mechanical engineering at the Technion, Israel, Institute of Technology, and head, Mechanical Engineering Department, at Ben Gurion University of the Negev, Israel. He was also adjunct professor of applied mechanics at the Illinois Institute of Technology (IIT) and director of engineering mechanics research at IIT's Research Institute. Dr. Sevin chaired the committee that produced the National Research Council report *Protecting Buildings from Bomb Damage* (National Academy Press, Washington, D.C., 1995). He recently served on a peer review group for the U.S. Army Corps of Engineers, Waterways Experiment Station, and the Defense Science Board's Task Force on Underground Facilities. Dr. Sevin has published extensively and has received a number of awards; in October 1998 he was the inaugural recipient of the DoD Shock and Vibration Information Analysis Center's Melvin L. Baron Award in structural dynamics and constitutive modeling. He earned a B.S. in mechanical engineering from IIT, an M.S. from the California Institute of Technology, and a Ph.D. in applied mechanics from IIT. He is a member of the American Society of Mechanical Engineers and the American Institute of Aeronautics and Astronautics and has served on numerous DoD and interagency committees.

Charles H. Thornton, NAE, is chairman of Thornton-Tomasetti Engineers/ the LZA Group, Inc., a 350-person organization that provides structural engineering and architectural services, failure analysis, hazard mitigation, and disaster response services. Dr. Thornton has provided expert witness testimony for many clients and is a recognized expert on collapse and structural failure analysis. He led the engineering investigation of the causes of the collapse of the Hartford Coliseum Space Truss Roof, the scaffold collapse at Pleasant Point Power Station, West Virginia, and the collapse of the New York State Thruway Schoharie Bridge. In 1996, he participated in the Federal Emergency Management Agency's Building Performance Assessment Team's investigation of the Oklahoma City bombing. Dr. Thornton is currently a visiting faculty member at Princeton University and Manhattan College; he has taught at Pratt Institute and Cooper Union. Dr. Thornton is a member of the Board of Trustees of Manhattan College, the Applied Technology Council, and the Building Seismic Safety Council. He holds a B.S. from Manhattan College and an M.S. and a Ph.D. from New York University.

B

Workshop Agenda

TUESDAY, NOVEMBER 28, 2000

8:00-9:00 am **Registration and Continental Breakfast**

9:00 am **Welcoming Remarks and Introduction of Keynote Speaker**
Mete Sozen, Purdue University; Chair, NRC Committee for Oversight and Assessment of Blast-effects and Related Research
Richard G. Little, Director, Board on Infrastructure and the Constructed Environment

9:15 am **Keynote Address: DoD/DTRA Role in Blast Mitigation Design**
Jay Davis, Director, Defense Threat Reduction Agency

9:45 am **Overview of the Blast Mitigation for Structures Program**
Douglas Sunshine, Program Manager, Defense Threat Reduction Agency

10:45 am **Break**

11:00 am **Charge to the Workshop Participants**
Eugene Sevin, Member, NRC Committee for the Oversight and Assessment of Blast-effects and Related Research

Plenary Session I—Owner/User Perspectives and Needs
Moderator: Stuart Knoop, Oudens & Knoop, Architects, PC

11:15 am **Government Building Owner's Perspective**
Wade Belcher, General Services Administration

11:40 am **Hazard and Consequence Management Needs**
Joseph Barbera, George Washington University

12:05 pm **Commercial Building Owner's Perspective**
Douglas Karpiloff, World Trade Center

12:30 pm-1:30 pm **Lunch**

Panel Session A—Owner/User Perspectives and Needs
Moderator: Stuart Knoop, Oudens & Knoop, Architects, PC
Co-Moderator: Douglas Karpiloff, Port Authority of New York and New Jersey

Panelists:
Wade Belcher, General Services Administration
Joseph Barbera, George Washington University
Patrick Collins, U.S. Department of State
Paul Senseny, Factory Mutual Research

1:30 pm **State Department Perspective**
Patrick Collins, Office of Foreign Buildings Operations, U.S. Department of State

2:00 pm **Insurance Industry Perspective**
Paul Senseny, Factory Mutual Research

2:30 pm **Discussion Between the Panel and Audience**

3:30-4:00 pm **Break**

Plenary Session II—Blast Resistant Design of Structures
Moderator: Robert P. Kennedy, RPK Structural Mechanics Consulting

4:00 pm **Moderator's Remarks**

4:05 pm **Protective Design Guides**
Edward Conrath, U.S. Army Corps of Engineers Protective Design Center, Omaha

4:30 pm **Navy Technology Developments**
Bob Odello, Naval Facilities Engineering Command, Naval Facilities Engineering Service Center

4:55 pm **Petrochemical Industry Design Experience**
Quentin Baker, Wilfred Baker Engineering, Inc.

5:20 pm **Commercial Structure Design and Assessment**
Jeremy Isenberg, Weidlinger Associates, Inc.

5:45 pm **Recess for the Day**

6:30 pm **Reception and Dinner—The Members Room**

Dinner Speaker: Christopher Veale, Security Advisor, Government of the United Kingdom
The British Experience in Improving the Blast Resistance of Buildings

WEDNESDAY, NOVEMBER 29, 2000

8:00-8:30 am **Continental Breakfast**

Plenary Session III—Architectural Perspectives
Moderator: Johanna LaPierre, RTKL Associates, Inc.

8:30 am **Architectural Challenges for Protective Design**
John F. Corkhill, American Institute of Architects

8:55 am	**Educating Architects to Address Protective Design Issues** Vivian Loftness, Carnegie Mellon
9:20 am	**Protective Glazing Design** Darrell Barker, EQE International
9:45 am	**Non-Structural Design Issues** John Chapman, Karn Charuhas Chapman Twohey, Architects
10:10-10:30 am	**Break**
10:30 am-12:30 pm	***Concurrent Panel Sessions*** ***Concurrent Panel Session B—Structural Designer Needs*** (The Lecture Room) Moderator: Robert Kennedy, RPK Structural Mechanics Consulting, Inc. Co-moderator: Reed Mosher, U.S. Army Engineering Research and Development Center Panelists: Quentin Baker, Wilfred Baker Engineering, Inc. Edward Conrath, U.S. Army Protective Design Center, Omaha Jeremy Isenberg, Weidlinger Associates Rudolph Matalucci, Sandia National Laboratories Bob Odello, Naval Facilities Engineering Command Loring Wyllie, Degenkolb Engineers
10:30 am	**Structural Retrofit for Blast Protection** Reed Mosher, U.S. Army Engineering Research and Development Center
10:50 am	**Needs of the Average Engineer for a Concerned Owner's Building** Loring Wyllie, Degenkolb Engineers
11:10 am	**Critical Facility Design Needs** Rudolph Matalucci, Sandia National Laboratories

11:30 am **Discussion Between the Panel and the Audience**

Concurrent Panel Session C—Building System Designer Needs (The Board Room)
Moderator: Johanna LaPierre, RTKL Associates, Inc.
Co-moderator: Eve Hinman, Hinman Consulting Engineers

Panelists:
- John F. Corkhill, American Institute of Architects
- Darrell Barker, EQE International
- John Chapman, Karn Charuhas Chapman Twohey, Architects
- Vivian Loftness, Carnegie Mellon University
- Douglas Mitten, Project Management Services, Inc.
- Kenneth Schoonover, Building Officials and Code Administrators (BOCA)

10:30 am **Code Considerations for Protective Design**
Kenneth Schoonover, BOCA

10:50 am **Cost Considerations for Decision Making**
Douglas Mitten, Project Management Services, Inc.

11:10 am **The Architect/Engineer Interface**
Eve Hinman, Hinman Consulting Engineers

11:30 am **Discussion Between the Panel and the Audience**

Concurrent Panel Session D—Emergency Medical and Rescue Needs (Room 180)
Moderator: Erik Auf der Heide, Agency for Toxic Substances and Disease Registry
Co-moderator: Joseph Barbera, George Washington University

Panelists:
- Josephine Malilay, Centers for Disease Control and Prevention
- Susan Mallonee and Sheryll Brown, Oklahoma State Department of Health

Anthony Macintyre, George Washington University
Eric Noji, Centers for Disease Control and Prevention

10:30 am **Epidemiology of Blast Injuries**
Susan Mallonee and Sheryll Brown, Oklahoma State Department of Health

10:50 am **Building Design for Injury Prevention**
Eric Noji, Centers for Disease Control and Prevention

11:10 am **Data Needs for Emergency Preparedness**
Josephine Malilay, Centers for Disease Control and Prevention

11:30 am **Facilitating Search and Rescue**
Anthony Macintyre, George Washington University

11:50 am **Discussion Between the Panel and the Audience**

12:30-1:30 pm **Lunch**

Plenary Panel—Technology Transfer for Protective Design (The Lecture Room)
Moderator: Sam Kiger, University of Missouri-Columbia
Co-moderator: William Hall, University of Illinois, Champaign-Urbana

Panelists:
Lawrence Bank, University of Wisconsin
James Grinar, Federal Emergency Management Agency
Jim Harris, J.R. Harris & Company
Joseph Tedesco, University of Florida
Christopher Rojahn, Applied Technology Council
Stanley Woodson, U.S. Army Engineering Research and Development Center

1:30 pm **Introduction and Remarks from the Moderator and Co-moderator**

1:55 pm	**Technology Transfer Activities at the American Institute of Steel Construction** Jim Harris, J.R. Harris & Company
2:15 pm	**Technology Transfer Activities at the American Concrete Institute** Stanley Woodson, U.S. Army Engineering Research and Development Center
2:35 pm	**Technology Transfer Activities at the American Society of Civil Engineers** Joseph Tedesco, University of Florida
2:55 pm	**Technology Transfer Activities at the Federal Emergency Management Agency** James Grinar, FEMA
3:15 pm	**Break**
3:35 pm	**Technology Transfer Experience from Earthquake Engineering** Christopher Rojahn, Applied Technology Council
3:55 pm	**A Center for Building-Vulnerability Science** Lawrence Bank, University of Wisconsin
4:15 pm	**Discussion Between the Panel and the Audience**
5:00 pm	**Recess for the Day**
5:30 pm	**Moderators and Co-moderators Meet to Prepare Panel Reports**

THURSDAY, NOVEMBER 30, 2000

8:00-9:00 am	**Networking Breakfast**
	Plenary Session IV—Workshop Wrap-up and Next Steps Moderator: Eugene Sevin, Consultant
9:00 am	**Panel A Report—Owner/User Perspectives and Needs** Stuart Knoop, Oudens and Knoop Architects, PC

9:20 am	**Panel B Report—Structural Designer Needs** Robert Kennedy, RPK Structural Mechanics Consulting, Inc.
9:40 am	**Panel C Report—Building System Designer Needs** Johanna LaPierre, RTKL Associates Inc.
10:00 am	**Break**
10:20 am	**Panel D Report—Emergency Medicine and Rescue Needs** Erik Auf der Heide, Agency for Toxic Substances and Disease Registry
10:40 am	**Plenary Panel Report—Technology Transfer for Protective Design** Sam Kiger, University of Missouri-Columbia
11:00 am	**Concluding Discussion and Comments**
12:00 pm	**Adjourn**

C

Workshop Keynote Address DoD/DTRA Role in Blast Mitigation Design

Dr. Jay Davis, Director
Defense Threat Reduction Agency

I truly appreciate the opportunity to give the keynote address at this workshop because this is a very, very important and vital subject for the Defense Threat Reduction Agency (DTRA) and we are pleased to sponsor this event. We are involved in all aspects of blast mitigation and the protection of people and buildings, both as a matter of professional pride but, regrettably, also as a matter of professional necessity.

As a result of the Khobar Towers bombing several years ago, the joint staff directed us to conduct security assessments of U.S. military facilities, both domestically and overseas. We put together teams to do assessments of terrorist opportunity for each base commander, including vulnerabilities of particular buildings and infrastructure, and mitigation measures that could be put in place. We would leave the commander with a fairly detailed study with suggestions of cost-effective things that could be done to begin to improve the security of the installation.

As you will hear, we have a very large experimental program both for making structures safer and for developing and understanding forensic techniques. The experiments that will be described are done partly to understand how to protect buildings and the people they shelter but also to understand how to work with the FBI and the other agencies if, after an event, we have to come in and provide some understanding of the weapon, the choice of employment, and perhaps even assist in identifying the perpetrators.

NOTE: Dr. Davis is currently working at Lawrence Livermore National Laboratory.

I also have a personal perspective, which might explain how I got started in this field. I would like a show of hands of those who have had their buildings bombed by a terrorist. Mine goes up, too, but I think I may have had the first experience. Thirty years ago I was a senior postdoctoral fellow in nuclear physics at the University of Wisconsin. In the furor of the Vietnam War, four high school dropouts in Madison stole a van, mixed 2000 pounds of ANFO [ammonium nitrate and fuel oil], parked it in the loading dock of my building, and set if off at 4 o'clock in the morning. So, I personally have worked the full spectrum of a terrorist bombing.

I have had the experience of crawling through my own building at 4 a.m., looking for friends, shutting down equipment, and spending days with the FBI with a sledgehammer slowly breaking up the three floors that fell into the basement, trying to understand what might have been the explosive material and its means of implantation. The building was rebuilt around us during the reconstruction of the laboratory and wasn't completed for 6 months, but we had our accelerator back up and running in 4 months and we were pretty proud of that.

As a consequence of terrorism, I have both lost friends and seen the change in friends' lives that these events produce. So, that may be one of the reasons why 30 years later a nuclear physicist stands in front of you running a defense agency that plays a fairly large role in counter terrorism and consequence management. This is a subject I care very greatly about.

Interestingly, during my years at Lawrence Livermore National Laboratory, I was an accelerator building and facility builder and am familiar with the sort of compromises you make between how much concrete is necessary, how the building looks, and what are the cost and effectiveness of different approaches. I had the useful experience of building in earthquake country, and so many of the design tradeoffs you make for blast mitigation, I have had to do as a designer and as an emergency manager in earthquake country. Finally, as an inspector in Iraq in the summer of 1991, I have had the interesting experience of looking at buildings on the other side that we put a fair amount of effort into damaging. So, for a physicist, I have both some practical experience and some pretty strong intuitive feelings about this business.

Those of you who are designers, builders, and operators have to deal with an immensely difficult subject. You have to work on the knee of one of the hardest curves I know, understanding how to make the proper investment for mitigation of low-probability but high-consequence events. When I came into this job at DTRA 2-1/2 years ago, I described the whole counter terrorism business as being on that peculiar knee on the curve where if nothing ever happens, you obviously wasted the money. If it does happen you hope you have done the best job possible of coping with the situation because you cannot afford to do the perfect job.

Unfortunately, this is likely to be a growth area and the community concerned with these issues will be busy for some time to come. Of course, if you are clever, the investment you make in blast mitigation can provide dividends in other areas as well. Structurally, I think this is obvious if you live in earthquake or tornado country because those events can load a building in a manner that, at first glance, can look like the effects of explosives. Another example, one that is not the business of this conference, is that if you think about the active defense of buildings against chemical and biological agents, you can begin to rationalize some pretty active and sophisticated air-handling systems to work against these threats if you also assess them in terms of the operational benefits they could provide against allergies and irritant avoidance, or simply in terms of improved building energy efficiency.

Now, the further you go down that road, the harder it becomes to substantiate the cost investment tradeoff, but I have done it. The steps from safety, to environmental protection, to health protection get to be harder to prove, but I think you must be sensitive to these ancillary benefits when you talk to the larger audience that isn't as familiar with the issues confronting the defensive design community. Your solutions are certainly going to have to address possible benefits in areas other than just blast mitigation, and you are going to have to find a way to express some of these other benefits. I think that is important.

You continue to face the general dilemma that we all do in the counter terrorism business and this is not a simple one—the threat is real but the threat is also ambiguous. The terrorist gets to pick the place, the time, and the means, and if they don't like what they see they can back away and wait for another day. You, on the other hand, get to design the building once, build it once, and then operate it from that day forward. Until you come back in and change the building, whatever you have put in place sits there static, and can, in fact, be studied if someone on the other side wants to take a run at you.

You are constrained by cost, by policy, and by the very hard realities of existing structures and building placements. This recognition of existing locational constraints is what led me to relocate DTRA to inside Fort Belvoir. I came to DTRA 2-1/2 years ago to build the defense agency and consolidate it at Dulles Airport. Two months after I started we hit the Bin Laden camps and I realized I had a combat support agency sitting in large glass boxes at the Dulles Airport and designed in such a way that anyone could have driven a car-bomb into the lobby. I had to go back to the Pentagon and say, "Folks, I am not particularly fearful, but if somebody ever makes a good run at us we will be laughed out of this business. You know, the agency that dare not say its name. If you are the Defense Threat

Reduction Agency and somebody car-bombs you, it is going to be real hard to hold your head up."

We are in the midst of a migration into Fort Belvoir, partly just to get a perimeter that we can control. At Dulles we were in commercial buildings on a site we did not control, under aesthetic constraints we had no vote in. So, we had to move—not easily done, but we have done it. The blast-mitigating activities are part of what's occurring on a much larger base and the cost/benefit analyses for new construction reflect this. There is compromise in almost any situation but I think you all realize you cannot afford the fiscal or political costs of retreating into bunkers. This is just not acceptable for public buildings in the United States.

If you think back to the late 1960s and early 1970s you may remember that the public face of the Bank of America changed in about 18 months. At that time, all banks had large glass windows, and for reasons I have forgotten, trashing Bank of America branches got to be a recreational activity of antiwar protestors. In the space of just a few years, Bank of America branches turned from glass-front buildings to basically brick fronts with one or two small rows of glass bricks that look sort of like vent slits.

The federal government cannot afford to take that approach. Bank of America backed away from it eventually, but I remember a very shocking transition when the bank simply felt it was driven into bunker mode. The U.S. government cannot do that with its public buildings, and those of you who operate private buildings cannot do it either.

Although I have an approach that is simple to state, it is not at all simple to execute. This is my message to you for this conference. You have to strive for appropriate and effective solutions that mitigate the credible risk. Unfortunately, defining the credible risk is a very, very hard part of your job. At the end of the day you cannot do everything. You are not going to be allowed to do everything and you cannot afford to do everything. The question you have to answer is a very hard one: Have you done enough? Not necessarily all that you can or could do, but you as the designers, the builders, the owners, and the operators of buildings have to live with your own answer to that question: Have you done enough to appropriately mitigate the dangers to the people who live in your structures?

Before we close, I think a very good question to consider is, What is the domestic obligation of the Department of Defense in these matters? This is a very tricky constitutional question in the United States because inside the boundaries of the country, DoD is, by and large, invisible, and for good reasons. Unique among the big democracies, we don't have a national police force. For that reason, counter terrorism is a little awkward for us because we properly delegate the police authority and the command authority very, very far down in our governmental system.

The phrase we use very guardedly and carefully in the Pentagon is that it is our obligation to appropriately extract every bit of information we can from DoD programs for the benefit of civil activities. We look very carefully for parallel activities or synergistic activities with other agencies. A very politically charged aspect of counter terrorism is in the chemical and biological defense program. Here the Department of Defense spends some $850 million a year on a program focused on defense of the war fighter but we very carefully seek to coordinate the research activities we fund in that program with the more civilly focused ones of DARPA and the Department of Energy.

I think my answer here is a fairly expansive one. We should show you what we are doing to implement our mission and our charter. The civil community should look at it for small modifications. For example, can you jump in free; can you add 5 cents to a $1 experiment and get something different from it? I think most of our data is readily available. The issue of availability of data comes up, but I think we would be looking for a statement from you about how can we make sure we try to meet as many of your needs as we can with the Blast Mitigation for Structures Program.

John Hamre, the former Deputy Secretary of Defense, really characterizes it very nicely. He says that if something bad happens domestically and the Department of Defense the next day is shown to have been irrelevant to civil disaster prevention even though it was working in those areas, we won't look very good and technically, we won't survive. We are conducting a program focused on the needs of the Department of Defense. Although I cannot fund a civil research program, it will be scandalous if we don't expand that program to deal with any possible civil questions that we can. My charge to you is that the civil design and building community needs to understand what we do in such a way that you can help us find some of those synergies, because we won't find them all.

D

Workshop Synopsis

SUMMARIES OF PRESENTATIONS

This appendix provides brief summaries of the presentations made at the November 2000 workshop. Following each summary is a locator key[1] indicating where the full presentation appears in PDF format on the CD-ROM that is included with this report.[2]

Welcoming Remarks

Richard Little, National Research Council

Richard Little, on behalf of the National Academies, welcomed the workshop participants, presented the background and agenda, and outlined the operational details for the workshop. He also summarized NRC publications in the area of protective design approaches, objectives of blast effects research, and a strategy for technology transfer. (9/801)

[1]For example, the locator designation (9/801) indicates that the presentation begins on page 9 of the PDF document.

[2]The workshop presentations were reproduced as submitted by their authors and were neither reviewed nor edited by the National Research Council.

DOD/DTRA Role in Blast Mitigation Design
Jay Davis, Defense Threat Reduction Agency

Dr. Davis's keynote address is included in this report as Appendix C. (14/801)

The Blast Mitigation for Structures Program
Douglas Sunshine, Defense Threat Reduction Agency

Douglas Sunshine described the general nature of the experimental blast studies currently underway. He cited DTRA's desire for NRC advisory and oversight efforts relating to the project and noted that this effort was a valuable part of the overall program. He expressed the hope that other workshop participants through their presentations, as well as the general discussion by all participants, would contribute to advancing the DTRA effort. He noted that at this time the experimental program consists of four major, focused investigations: debris hazard, prevention of progressive collapse, injury modeling, and mailroom testing.

Among the major objectives of the work is defining what information is necessary for the typical engineer and what form it should be in for ease of use. He pointed to releasability of data as one of the difficult problems associated with the experimental program, involving how to reconcile the potential advantage terrorists may gain from having access to knowledge, with the need for knowledge to enhance protection. Information on vulnerability assessment, design guidance, and test data are needed for force protection and to ensure overall federal, military, and commercial building protection. He discussed the extensive glazing-related test program that has been carried out, described the complex and dangerous role of blast debris generally, and reviewed the structures program, with reference to walls and columns. One goal is to develop retrofitting techniques, better column design, and approaches for component blast validation (assessment of performance). (21/801)

Charge to the Workshop Attendees
Eugene Sevin, Consultant

Eugene Sevin commented first on the diversity of the workshop's attendees, namely building owners, users, architects, designers, and members of allied professions of many types; he noted that this diversity was a definite plus for the success and usefulness of the workshop. He described the role of the workshop panels, as it encompassed panel participant presentations and discussion, pointing out that the focus should be on information needs, test gaps, and technology transfer approaches. He emphasized the importance of the moderator summaries to be delivered verbally and in writing at the end of the workshop. (88/801)

Security Sensitive Building Design for Urban Settings
Wade Belcher, General Services Administration

Wade Belcher centered his presentation on four topics common to GSA building and construction activities, namely multiple risks, competing goals, myriad constraints, and the application of reasonable, probable, and certain measures. He reviewed reports, major panels, Department of Justice report recommendations, GSA security design criteria, and the many other actions taken by the agency to improve practice and comply with Federal Executive Order 12977, Enhancement of Security in Federal Buildings. (90/801)

Consequence Management Needs
Joseph A. Barbera, George Washington University

Joseph Barbera presented an overview of the human impact of large explosions, the need for understanding the factors important to minimizing injuries and death as a primary action, maximizing rescuer safety as a secondary action, and maximizing response effectiveness. He noted that the hazards are many and complex—for example, blast effects, shrapnel and falling or flying objects, structural collapse, smoke, fire, toxic gases, and hazardous materials and dust. (117/801)

Protecting People and Buildings from Bomb Damage from the Commercial Owner's Perspective
Douglas G. Karpiloff, World Trade Center

Douglas Karpiloff began his presentation by describing the magnitude of the World Trade Center complex. For example, 100,000 people per day traverse the complex and the 11 million square feet of office space house 450 tenants with 50,000 employees. Of special interest was his description of the approaches adopted to accommodate car and van access to services, and the personnel management activities. He listed the challenges confronting the owners at the time of the blast in 1993 and described a sampling of the measures adopted to achieve their security objectives. (152/801)

U.S. Department of State–Facilities Abroad––
Office of Foreign Building Operations
Patrick Collins, U.S. Department of State

Patrick Collins addressed four topics: current issues, design challenges, some current design approaches, and new methods and tools employed. He outlined the appropriations and capital funding provided for his unit's activities over a period of years. Of great technical interest were cost comparisons for standoff distance and relative hardening in the most general sense, followed by breakdowns of the costs for roofs, walls, and security items. He indicated an immediate need for new bollard design tools, refined standoff design concepts, existing building renovation solutions, better window glazing products, forced entry improvements, and new materials research and implementation. (172/801)

Insurance Perspectives
Paul Senseny, Factory Mutual Global

Paul Senseny began by listing the kinds of insurance that insurance companies generally offer, for example, property, casualty, and liability insurance. Factory Mutual offers global insurance on commercial, industrial, and residential property. Terrorism is covered, with the exception of nuclear events. He presented the concept of highly protected risk (HPR), which is incorporated in policies written for situations involving prudent risk management, and also spoke about pricing. Typically such insurance is written for property damage, business disruption (examples being loss of market share, corporate image, public image, reputation for reliability, and ability to retain employees), and uninsurable losses. He summarized with four points: (1) property insurance is a conduit for identifying such matters as uninsurable losses; (2) the underwriting industry needs a loss expectancy methodology; (3) design standards need improved mitigation technology; and (4) approved products used by the insurance industry need some test protocols. (203/801)

Protective Design Guides
Ed Conrath, U.S. Army Corps of Engineers, Protective Design Center

Ed Conrath described the activities of the U.S. Army Corps of Engineers, Protective Design Center, which consist generally of force protection (for example, physical security and antiterrorism) and guidance for hardened structures (including design against conventional and nuclear weapons effects, C/B/R design, and explosive safety design). He described some of the government tools that are used by his group. (215/801)

Navy Technology Developments
Robert Odello, Naval Facilities Engineering Service Center

Robert Odello described the design technology used in the new high-performance magazine facility; the relationship of these design principles to bomb damage protection; and examples of technical implementation. (244/801)

Petrochemical Industry Design Experience
Quentin A. Baker, Wilfred Baker Engineering, Inc.

Quentin Baker described the numerous explosive hazards that exist in the chemical and petroleum refining industry, such as vapor cloud explosion, runaway reactions in a condensed phase material, bursting pressure vessels, and terrorist threats. He described in some detail the risk management (and assessment) philosophy employed by these industries with respect to design and operation, as opposed to the philosophy of governmental regulation. (263/801)

Commercial Structure Design Experience
Jeremy Isenberg, Weidlinger Associates, Inc.

Jeremy Isenberg provided examples of terrorist attacks in recent years and described some of the principles basic to experimental testing and computational simulation and assessment. He stated his belief that 75 percent of the design effort could be accomplished by so-called simplified methods, while the remainder required advanced computation and modeling. He described in some detail the capabilities of the Weidlinger program, FLEX. (277/801)

Counter Terrorist Protective and Security Measures for Government Buildings in the United Kingdom
Christopher Veale, U.K. Government

Christopher Veale discussed the incorporation of protective design features into standard measures (those applied to all government buildings) and enhanced measures (those applied in specific cases). Standard measures apply, for example, to structure, glazing protection, bomb shelter area accommodation, access control, counter-terrorist contingency plans, and x-ray screening. He also provided examples of the disciplines affected by such measures to indicate the complexity and cost of such actions. Of particular interest was his description of glazing damage that has occurred in the United Kingdom, and information provided on protective measures. (307/801)

Architectural Challenges for Protective Design
John Corkhill, American Institute of Architects

John Corkhill discussed alternatives for protective design in the context of the closing of Pennsylvania Avenue in front of the White House. He presented an alternative design for a blast barrier to provide the requisite level of protection. He stressed the need for consideration of all options for protective design solutions. (No written presentation was provided.)

Protecting People and Buildings from Bomb Damage
Vivian Loftness, Carnegie Mellon University

Vivian Loftness described the practical difficulty of addressing chemical and/or biological threats in building design. As counterpoint, she presented an interesting compendium of deaths from a range of hazards, followed by a description of "sick buildings" currently being constructed. She concluded with several examples that could lead to improved building design. (340/801)

Protective Glazing Design
Darrell Barker, EQE International

Darrell Barker provided detailed insight into the problems associated with glazing design and performance under blast conditions. His presentation covered a range of subjects, such as loading, protection requirements, protective glazing options, design considerations, and resources. (361/801)

Blast Resistant Technology That Architects Need
John W. Chapman, Kern Charuhas Chapman & Twohey

John Chapman described the blast protection parameters typically applied to buildings designed by his firm; 30 psi to 140 psi blast pressure for new buildings and 3 psi to 15 psi blast pressure for building retrofits. His presentation focused on the blast protection problems confronting architects and the need for a range of possible solutions. He particularly noted the desire for product test results and performance standards for various aspects of blast-resistant design. (418/801)

Structural Retrofit for Blast Protection

Reed Mosher, U.S. Army Engineering Research and Development Center

Reed Mosher said that the objective of blast-related research being carried out at the Engineering Research and Development Center is preventing structural damage, property damage, and human injury and loss of life. The test and analysis programs center on studies of structural collapse and blast debris. He presented some data from tests and described the capabilities of several computational tools, such as HAZL, and others. (446/801)

Needs of the Average Engineer for a Concerned Owner's Building

Loring A. Wyllie, Jr., Degenkolb Engineers

Loring Wyllie summarized issues arising during the planning of a commercial building that affect protective design. These issues include the owner's desire to prevent incidents, the need to be customer-friendly and to minimize barriers and other security-related constraints, real estate limitations, and cost factors. The design options available to the typical design engineer are seismic-resistant design or enhancements of structural integrity. He emphasized the need for additional design guidance. (514/801)

Critical Facility Design Needs (U.S. Department of Energy) . . .
An Architectural Surety Perspective

R.V. Matalucci, Sandia National Laboratories

Mr. Matalucci indicated that the Department of Energy is both a user and a developer of security protection techniques and products. Sandia National Laboratories specializes in vulnerability assessment coupled with the use of applicable risk-reduction procedures. He provided some general examples of ongoing activities. (522/801)

Code Considerations for Protective Design

K.M. Schoonover, BOCA International, Inc.

Mr. Schoonover noted at the outset of his presentation that commercial building codes do not include consideration of blast-resistant design. He discussed in some detail the overlapping, and differing, nature of provisions in the codes and provisions for blast design and addressed some cost issues. (533/801)

Cost Considerations for Decision Making
Douglas Mitten, Project Management Services, Inc.

Douglas Mitten described the critical role that cost plays in decision making for protective design and presented a number of cost models for displaying and analyzing options. He emphasized that designers and decision makers can improve their understanding and handling of protective design measures by examining accurate models of initial costs, operations and maintenance costs, and benefit costs. The models enable comparison of countermeasures with other investment alternatives. (535/801)

Bomb Blast Mitigation
Robert Smilowitz, Weidlinger Associates

Robert Smilowitz described a process for the integration of the four essential aspects of blast design: (1) definition of the threat, followed by risk analysis, (2) coordinated comprehensive protective design, (3) analysis and design of structural systems and components, and (4) design documentation. (544/801)

Epidemiology of Blast Injuries
Sue Mallonee and Sheryl Brown, Oklahoma State Department of Health

Sue Mallonee and Sheryl Brown summarized data from six major studies of the Murrah Building bombing in Oklahoma City. The data surveyed included hospital medical records, physicians' records, building occupant records, newspaper records, governor's records, and survivor memories and records. Their presentation demonstrated that thorough epidemiological analysis can improve the physical design of facilities subject to terrorist bombings. (555/801)

Khobar Towers Bombing Injury Epidemiology
Sheryl Brown, Oklahoma State Department of Health

Sheryl Brown presented the results of the injury epidemiology study for Khobar Towers. This survey was carried out through a confidential mail survey, review of medical records, and injury mapping. Data was presented on the types and causes of injuries. (583/801)

Building-related Issues and Injury Control
Eric K. Noji, Centers for Disease Control and Prevention

Eric Noji presented the results of several studies of earthquake damage sustained throughout the world. Better understanding of the building factors associated with various types of excitation that lead to structural collapse can be used to reduce potential injuries and death in buildings subject to bombing attack. (604/801)

Data Needs for Emergency Preparedness
Josephine Malilay, Centers for Disease Control and Prevention

Josephine Malilay described the many factors involved in emergency preparedness and the role of planning in reducing injuries and death. She also described data needs, multidisciplinary roles of the planning and response team, the need for coordination and management, and the value of epidemiological methods. (669/801)

Blast Mitigation for Structures: Facilitating Search and Rescue
Anthony Macintyre,
Fairfax County Urban Search and Rescue Task Force

Anthony Macintyre described his experiences onsite at the Nairobi embassy bombing. He described two classes of victim and rescuer in these situations and the need to relate rescue methods to the likely levels of injury. (692/801)

Blast Resistant Potential Issues for Civilian Steel Construction
James Harris, J.R. Harris & Co.

James Harris made some general qualitative comments about blast issues associated with buildings and then described the activities of the American Institute of Steel Construction's committee on blast-resistant design of steel buildings. This committee is attempting to develop guidelines for steel construction and is focusing on blast sources, structural components affected (cladding/glazing) and load transmission, risk issues, and cost and effectiveness of addressing the hazard. (696/801)

Technology Transfer Activities at the American Concrete Institute
Stanley C. Woodson,
U.S. Army Engineering Research and Development Center

Stanley Woodson discussed the activities and plans of American Concrete Institute Committee 370, Shock and Vibratory Load Effects. His presentation addressed design philosophy, types of structures, materials, loads and deformations, design requirements, and openings. Committee

370 plans to write a design guideline document with commentary. (715/801)

Technology Transfer Activities at the American Society of Civil Engineers' Structural Engineering Institute
Joseph W. Tedesco, University of Florida

Joseph Tedesco reviewed recent and upcoming conference activities, committee reports, and technology-transfer initiatives of the Shock and Vibratory Effects Committee of the American Society of Civil Engineers' Structural Engineering Institute to address blast effects on structures. That committee is also considering the possibility of preparing independent codes, standards, or design manuals and incorporating some of this type of material into ASCE 7-98, Minimum Design Loads for Buildings and Other Structures. (727/801)

Technology Transfer at the Federal Emergency Management Agency
James Grinar, FEMA

James Grinar described technology transfer mechanisms used by FEMA and a recent conference focused on technology for hazard mitigation. He indicated that future funding for these activities had not been identified. (736/801)

Technology Transfer Experience for Earthquake Engineering
Christopher Rojahn, Applied Technology Council

Christopher Rojahn provided a short overview of earthquake engineering in the United States that touched on its history, the impetus for technology transfer, institutional players, mechanisms and formats, and examples of products and successful technology transfer efforts. The Applied Technology Council has played an important role in technology transfer in the earthquake engineering field. (737/801)

A Center for Building-Vulnerability Sciences
Lawrence C. Bank, University of Wisconsin

The goal of the proposed center for building-vulnerability sciences focuses on reducing the vulnerability of buildings to technological hazards through the development of structural and architectural systems, air-handling and ventilation systems, water distribution systems, and communication and power systems that improve building performance. The organizational and operating concept for the center is to treat the building as a living organism. (753/801)

PANEL AND PLENARY SESSION SUMMARY REPORTS

Owner/User Perspectives and Needs Building System Designer Needs

Stuart Knoop, Moderator, Oudens and Knoop, PC

Stuart Knoop began his summary of the two panels' presentations and discussions by pointing out that terrorist bombing is a very low probability event, which makes it difficult to justify protective design measures to a commercial or civilian government building owner. Budgets are rarely large enough to fund all protective measures, and the insurance industry will not provide incentives. One way of addressing this issue is to seek multihazard solutions that address seismic and extreme wind events in addition to blast. This approach will enhance the benefit/cost ratio and make implementation of blast-related improvements more likely. Research is needed on site perimeter issues such as the effectiveness of various types of vehicle barriers and their cost-effectiveness versus other types of perimeter control. Information on how to design building openings such as doors and windows, what products meet performance standards, and how cladding behaves in a blast environment are also candidates for research. Collateral effects such as debris hazards, lifeline systems, and blast field effects on adjacent structures were also identified. Finally, there is a need for a unified approach for protective design that is well-understood and accepted by the design professions. (764/801)

Structural Designer Needs

Robert Kennedy, Moderator, RPK Structural Mechanics Consulting

Robert Kennedy pointed out the overriding interest in obtaining access to protective design guidelines, with an emphasis on obtaining up-to-date technical design manuals that are in the public domain. There is also an interest in obtaining simplified design guidance for cost-effective approaches to providing lesser to moderate levels of blast protection. This includes specific guidance on approaches to and criteria for providing reasonable protection against progressive collapse from moderate-size events and cost-effective glazing of window glass, methods for attaching glass to the frame, and techniques for attaching the frame to the wall. A great deal of emphasis was placed on the need for tested products that meet well-understood and accepted performance standards. Test data should also be available. Risk management techniques for performing tradeoff analysis were also identified as desirable. (769/801)

Emerging Medical and Rescue Needs

Erik Auf der Heide, Co-moderator,
Agency for Toxic Substances and Disease Registry
Joseph Barbera, Co-moderator, George Washington University

The problems identified during this panel session included (1) failure to collect perishable injury and health data that may be used to save lives in future incidents; (2) difficulty obtaining data that has been compiled on past bombings; (3) buildings that are designed with little consideration for the needs of search and rescue; (4) lack of knowledge about a building's design, utility shutoffs, the locations of occupants, and hazards as impeding search and rescue; and (5) the dependence of successful search and rescue efforts on rapid on-site assessment of the building's structural integrity. Several possible solutions to these problems were put forward by this panel, including establishing a multidisciplinary rapid response (health and engineering) data collection team (analogous to the National Transportation Safety Board's postcrash investigation team) and defining standardized data collection methods and data elements for these teams to use; establishing a national or international clearinghouse for past and future data on bomb blast incidents; and establishing a process for developing and disseminating best practices in building design with input from the public safety community. Also needed is up-to-date information on building services, such as water and natural gas shutoff valves, or the presence of asbestos, and a process for identifying this information and making it available to rescuers. There is also a need to provide training in rapid, postimpact structural assessment. (772/801)

Technology Transfer for Protective Design

William J. Hall, Moderator, University of Illinois at Urbana-Champaign

The primary issue to be addressed by the workshop—how to expedite the transfer of significant militarily derived blast loading and blast resistance information, plus related information, into the public sector—includes such typical areas of concern as threat levels, dynamic loading parameters, resistance schemes, modeling, analysis, radiation protection (if applicable), construction, quality assurance and quality control, inspection, maintenance, protection of occupants (humans and equipment) from airblast and shock, and ingress and egress (including emergency escape). Overall design considerations include simplicity and protection against multiple hazards (earthquakes, wind and tornado, debris, and storms with a potential for causing flooding). The tools for accomplishing technology transfer and/or educating professional staff in blast design include manuals, guidelines, and miscellaneous publications; video (live and tape); distance learning courses and lectures (available from universities and corporations); workshops, seminars, short courses, and self-study (through the use of manuals and video resources); and consultants (when special help is required). The role of education and training in multihazard facets of design for architects and engineers was discussed at several points in the presentations and discussion and was suggested as a way to incorporate some basic education about topics related to blast design. Examples might include blast/shock, wind/tornado, seismic, volcanic dust, rain/ice/snow and flooding, toxic contamination, and biological and chemical hazard considerations. With respect to the DTRA program, and activity underway or to be undertaken in the future, it was observed by several participants that it might be most profitable to concentrate on small pieces of the overall program and issue summary studies related thereto. Examples might include siting, land, and facility features; safe haven aspects of building design; security issues, including access; other design concerns such as ingress/egress, blast doors, air supply and protective blast vents, floor, roof, walls and frames (if applicable); and glazing and supporting frames. (795/801)

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Selected Annotated Bibliography on High Explosive Blast Design and Analysis

Compiled by

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The following list is a brief summary of literature that was reviewed in preparation for the workshop "Protecting People and Buildings from Bomb Damage," held at the National Academy of Sciences in Washington, D.C., on November 28-30, 2000. It is not intended to be exhaustive. The reader should note that some of the references cited in documents included in this summary are restricted in distribution to "U.S. Government agencies and their contractors" and may not be readily available to the general public.

1. *Blast and Ballistic Loading of Structures*, by P.D. Smith and J.G. Hetherington, published by Butterworth/Heinemann, 1994 [ISBN: 0-7506-2024-2]. This is a sound British book with good information on loading and modestly good material on resistance. A copy purchased recently through a book dealer cost $138 and took about 6 weeks to arrive.

2. *Blast Effects on Buildings*, edited by G.C. Mays and P.D. Smith, published by Thomas Telford and available only through American Society of Civil Engineers, 1995 (Stock 2020) [ISBN: 0-7277-2030-9]. This, too, is a British book, but is not as comprehensive as item (1) above. The cost through ASCE is about $48 plus shipping (member cost is less).

3. *Concrete and Blast Effects,* edited by William Bounds, American Concrete Institute, SP-175, 1998. Available from ACI only. An

interesting and informative collection of contributions in the reinforced concrete field. The cost is about $52.50 plus shipping (less for members). One would normally want the latest version of the ACI-318 Specification, and the accompanying PCA interpretation [1000 pages], a total package available for about $120 to members. Nonmembers pay slightly more.

4. *Design of Blast Resistant Buildings in Petrochemical Facilities,* Task Committee on Blast Resistant Design, Petrochemical Committee of the Energy Division, ASCE, 1997 (Stock 40265) [ISBN: 0-7844-0265-5]. A reasonably good publication on the subject. The cost from ASCE is about $40 plus shipping (less for members).

5. *Design of Structures to Resist Nuclear Weapons Effects,* ASCE Manual No. 42, 1985 [ISBN: 0-87262-439-0]. Although the title contains the word "nuclear," many of the relationships and plots shown are applicable to high explosives as well. The resistance material has application in many respects to the HE case as well. The price is not known; available from ASCE.

6. *Explosion Hazards and Evaluation* by W.E. Baker, P.A. Cox, P.S. Westine, J.J. Kulesz, and R.A. Strelow, Elsevier Scientific Publishing Co., 1983. Out of print. A major book with a wealth of information; can be found in many libraries. Still cited in specific studies. An impressive reference.

7. *Protecting Buildings from Bomb Damage,* National Research Council, 1995. This is the report of a committee charged with reviewing the knowledge base on blast-effects mitigation technology, assessing the applicability of the technology to civilian buildings, and recommending courses of action for technology transfer. It is available as a publication on-demand for $21.40 from the National Academy Press at <http://books.nap.edu/catalog/5021.html>.

8. *Structural Design for Physical Security*, Task Committee under SEI/ASCE. Edited by E.J. Conrath, T. Krauthammer, K.A. Marchand, and P.F. Mlakar, 1999 (Stock 40457) [ISBN: 0-7844-0457-7]. A reference whose various chapters have a differing focus. The cost through ASCE is about $24 plus shipping (less for members).

9. *Structures to Resist the Effects of Accidental Explosion,* Army TM 5-1300, 1990 Edition. This is the standard design manual for pro-

tective construction and establishes design procedures and construction techniques, blast load parameters, and methods for calculating dynamic response.

10. *Structures Under Shock and Impact II,* edited by P.S. Bulson, 1992, 688 p. [ISBN: 0-7277-1681-6]. This is the proceedings of a conference held in Portsmouth, England, in 1992. The papers are generally theoretical and are of only limited value to designers. The cost is £95 (British) from Thomas Telford Services Ltd. in London.

11. *The Embassy of the Future*, National Research Council, 1986. The report of a committee charged with developing design criteria for the model embassy building. The recommendations address security-related issues in virtually every aspect of the planning, design, construction, and management of buildings at risk. It is out of print but can be read online at <http://books.nap.edu/catalog/9806.html>.

12. *The Protection of Federal Office Buildings Against Terrorism,* National Research Council, 1988. A study undertaken at the request of a collection of federal agencies, its primary focus is how to improve the security of existing buildings subject to terrorist attack. It is out of print but can be read online at <http://books.nap.edu/catalog/9808.html>.

13. *The Structural Engineer's Response to Explosion Damage,* Institution of Structural Engineers, Great Britain, 1995. A short (20 pages) and good general introduction to damage from bombs. It is based largely on experience with the effects of terrorist vehicle-bombs in British cities. It is well illustrated but contains no analytical data. It is available from the Institution of Structural Engineers, London, for £25 (British).

14. *Lessons from the Oklahoma City Bombing: Defensive Design Techniques*, by E.E. Hinman and David J. Hammond, American Society of Civil Engineers, New York, ASCE Press, 1997. This report describes the bombing of the Alfred P. Murrah Federal Building, the damage it caused, and the roles of those involved in the rescue and recovery operation. Of particular interest are a discussion of the investigation of progressive collapse, a comparison of the characteristics of seismic and blast events, and a description of basic defensive design principles. It also contains a bibliography

that lists relevant military manuals, technical reports, papers, and texts.

15. "Security," by Roy Spillenkothen and Ronald J. Massa, in *Facility Design and Management Handbook,* edited by Eric Teicholz, McGraw-Hill, 2001. This brief overview focuses on bomb attacks and bomb threats. It contains a description of explosives and blast effects and some photos of the results of bombing attacks from around the world. It also presents a five-point bomb defense program that is useful as a defensive design primer.

16. *Explosives Engineering,* by Paul W. Cooper, Wiley-VCH, 1996. This text presents the basic technologies used in the engineering of explosives and explosive systems. It covers the chemistry of explosives, energetics, shock waves, detonation, and initiation.